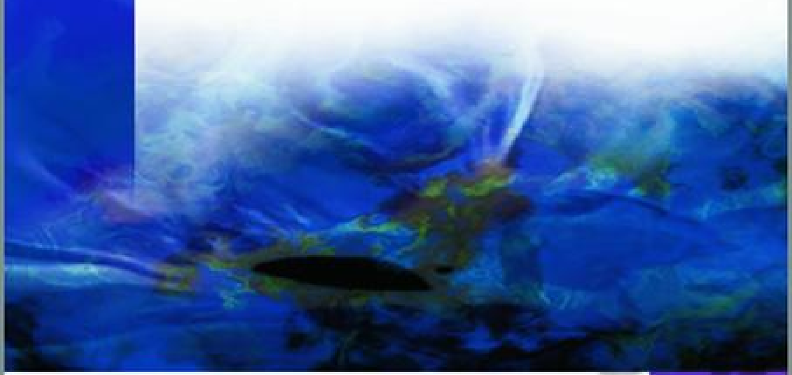
A. IAN GLENDON
SHARON G. CLARKE



HUMAN SAFETY AND RISK MANAGEMENT

A PSYCHOLOGICAL PERSPECTIVE

THIRD EDITION

CRC Press
Taylor & Francis Group

HUMAN SAFETY AND RISK MANAGEMENT

A Psychological Perspective

THIRD EDITION

HUMAN SAFETY AND RISK MANAGEMENT

A Psychological Perspective

THIRD EDITION

A. IAN GLENDON
GRIFFITH UNIVERSITY, QUEENSLAND, AUSTRALIA

SHARON G. CLARKE
MANCHESTER BUSINESS SCHOOL, UNIVERSITY OF MANCHESTER, UK

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20150904

International Standard Book Number-13: 978-1-4822-2057-5 (eBook - PDF)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

Acknowledgments

We thank the publisher's staff for their patience in helping us to reach our final target for this third edition of the book. We appreciate and thank the following people for reading and commenting on draft sections: Trevor Hine, Patrick Murray, Ali Salajegheh, and Alan Waring. We acknowledge Eugene McKenna, whose original idea sparked this project, and who was our coauthor on the first two editions of *Human Safety and Risk Management*.

Ian Glendon expresses his enormous gratitude to his wife Mimi for her constant support, love, and understanding.

Sharon Clarke acknowledges the support of her family, particularly her husband Peter Axworthy and children Emily Rose and Sam, as well as her colleagues and students at Manchester Business School.

Authors

A. Ian Glendon is at the School of Applied Psychology, Griffith University Gold Coast Campus, Queensland, Australia. His research interests include risk management, safety culture, occupational health and safety, personality and safe behavior, and driver behavior/driver stress. Apart from coauthoring the previous two editions of *Human Safety and Risk Management*, he has more than 100 refereed publications and 3 books, with his work being extensively cited. He has supervised more than two dozen research higher degree students and completed numerous research contracts. He has consulted for more than 80 clients on topics including safety culture, accident/incident analysis, task analysis, human error/reliability analysis, and safety auditing. He is an elected fellow of the International Association of Applied Psychology (IAAP) and of the Institution of Occupational Safety and Health. His other professional memberships include Chartered Occupational Psychologist (United Kingdom) and Chartered Ergonomist & Human Factors Specialist (United Kingdom). He is a former president of the IAAP Division of Traffic and Transportation Psychology.

Sharon G. Clarke is professor of organizational psychology at Manchester Business School, University of Manchester, Manchester, United Kingdom. She earned a first-class BA in psychology (1990) and a PhD in organizational psychology (1993) before becoming a lecturer in applied psychology at Aston University. She later joined UMIST (now the University of Manchester) in 1996. She has research interests in safety culture, safety climate, leadership, personality, occupational stress, well-being, and health. Her work has been widely published in leading academic and practitioner journals, national and international conferences, and coauthored and edited books. She has held a number of funded research grants, including from the Institution of Occupational Safety and Health, UK government grants, and industry funding. She is currently an associate editor for the *Journal of Occupational and Organizational Psychology* and the *Journal of Occupational Health Psychology*, and is on the editorial board of the *International Journal of Stress Management*.

chapter one

Introduction

Science has produced many new discoveries since the first edition of this book appeared in 1995. Apart from its general structure, nothing remains from that first edition and very little from the second edition. Nearly all the material used for the first edition was only available in printed form, while references had to be individually and laboriously word processed. Nowadays the database "cite" function makes compiling reference lists much less onerous. Powerful search engines have made finding relevant information much easier. Vastly enhanced access to information and the speed with which it can now be located make it imperative to adequately represent the findings from this feature of contemporary communication. Enhanced availability of knowledge has correspondingly increased authors' responsibility to ensure that their material is up-to-date and highly germane to their specialist topic. The rate at which knowledge advances in many areas of science means that this is an increasing challenge, particularly in cases, as in ours, where we seek to represent relevant new knowledge across a range of disciplinary areas. These features have also shortened the lead time between laying the foundations for a new edition and its publication.

As an adjunct to the increased availability of scientific literature and applied studies, the impetus for this third edition also extends beyond the implicit drivers of the two previous editions. Our current philosophy includes (1) recognizing the increased globalization of knowledge and its impact, (2) a focus that is broader than the world of work, (3) acknowledgement of positive as well as negative aspects of risk, (4) not being tied to a purely formulaic approach to our subject matter, and (5) expanding explanations of safety and risk issues that incorporate multiple levels. This latter feature includes neural, through cognitive and behavioral, to social, organizational, and wider community or political influences. For example, at an individual microlevel, concepts such as risk, threat, safety, and reward can be represented by neuronal activation, which enhances our understanding of processes of sensation and perception. At a macrolevel, the growing number of national and international standards on many safety and risk-related issues testifies to increased attention by many jurisdictions and global agencies to ensure that organizations and countries are primed to incorporate best practice within their policies and operations. In between, individual, group, and cultural variables impact safety and risk issues in a myriad ways. The multilevel approach is represented in Figure 1.1.

The need to represent contemporary scientific advances was stimulated, inter alia, by one reviewer comparing parts of the first edition with an undergraduate textbook! Our aim in this third edition is to reflect current scientific research across a range of disciplines as it applies to human safety and risk management. That we were at least part way toward that goal was confirmed by a reviewer of the second edition, who applauded our emphasis on the scientific literature. Much relevant research has been published in the 9 years since the second edition appeared, and we have sought to represent this in the current edition. We have generally deliberately eschewed repeating information and many of the applications that featured in the second edition, for example, human factors design features to minimize the effects human error, on the grounds that these remain valid and accessible

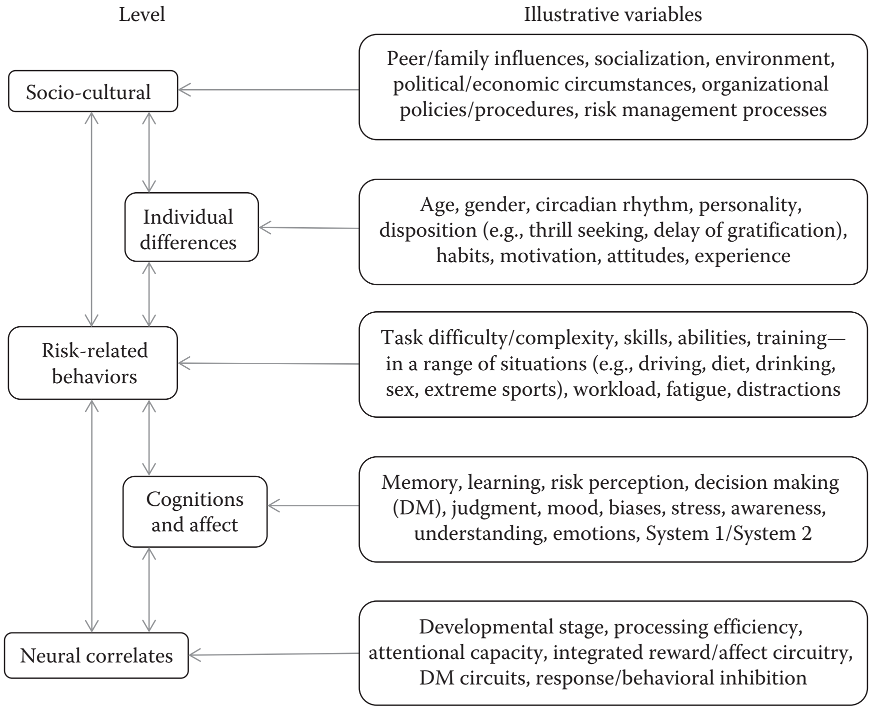


Figure 1.1 A multilevel framework for exploring human safety and risk management.

via the second edition. This third edition focuses more on understanding underlying principles associated with human safety and risk management.

While all disciplines and subdisciplines relevant to safety and risk have advanced in the years since the second edition, three in particular are notable in terms of their impact upon our third edition. First, the evolutionary perspective, while it has been a useful framework for understanding much human behavior for a considerable time, is now providing explanations for an array of human actions and cognitions extending to areas that were until recently conceived of quite differently. Two examples of the evolutionary influence are the incorporation of emotion into risk decisions and actions that reflect ecological rationality, which replaces bounded rationality type explanations of previous eras, and the rerepresentation of "cognitive biases" as another aspect of ecological rationality that is based upon greater understanding of evolutionary processes.

The second area in which extensive and rapid advances continue to be made is neuroscience, including cognitive neuroscience, which has facilitated the foundation layer in Figure 1.1. Rapid advances in brain scanning and imaging techniques have generated a vast increase in scientific discoveries. Neuroscience can provide an additional layer of understanding for a range of cognitive, emotional, and behavioral processes. Rather than supplanting our prior and parallel knowledge, they expand it in ways that previous generations of scholars might have considered barely possible. While some traditional social scientists have referred to such an additional layer as a "reductionist" approach, the value of such developing knowledge lies in enhancing our depth of understanding of many cognitive and behavioral features that were formerly consigned to "black box" type explanations. Recognizing the limitations on the number of layers that it makes sense to present, while we have accessed the neural level when doing so can increase understanding of a phenomenon, we have rarely entered a terrain below this level. For example, the physiology of chemical processes, particularly hormonal action, is touched upon only cursorily. However, as this is not a neuroanatomy text, interested readers can access any number of websites providing guidance on the locations of the neuroanatomical brain features* referred to in Chapters 2, 4, and 5.

The third area in which rapid progress has been made is in the theoretical aspects of risk management (RM) and its derivatives (e.g., risk governance, risk communication). Many traditional notions of risk and its management have been overturned in recent years as new conceptual models and applications have been developed in a swathe of disciplinary areas, many of which are considered in detail in Chapter 11. In addition to a horizontal interconnectedness across a variety of RM domains, our primarily psychological approach adopts a vertical representation of how risks are sensed, perceived—cognitively and affectively—and how organizational, social, and broader influences impact their interpretation.

An example of an area in which knowledge at all five levels can provide a comprehensive perspective on an area of concern in the risk literature is the well-documented elevated levels of risk-taking (R-T) behavior during adolescence (Braams, Leijenhorst, & Crone, 2014). At the behavioral level, numerous studies attest to the varieties of R-T behavior engaged in by many adolescents, including driving fast, unsafe sexual practices, drug experimentation, and extreme sports. At the individual differences level, studies have revealed that as well as age, personality traits (e.g., sensation seeking, impulsivity) are associated with risky and reckless behaviors, as well as that young males' R-T behavior on average far exceeds that of young females (Luna, Padmanabhan, & Geier, 2014). At the topmost level of our model, research has found that compared with family or mentoring environments, social situations involving adolescents' peer groups are much more likely to create R-T scenarios. At the cognitive level, it is known that risky behaviors are preempted by risky choices in decision-making tasks. At the neuroscience level, a number of models reflect the comparative developmental rates of cortical and subcortical brain regions, which can account for observed phenomena at the other levels. An evolutionary envelope rounds off the explanatory framework. These issues are explored further in the chapters comprising this volume.

This third edition of *Human Safety and Risk Management*, inter alia, includes an expanded chapter on the human sensory system (HSS), the rationale for which includes the following:

1. We rely on our senses for all behaviors engaged in as well as the cognitive and emotional basis for those behaviors, including those associated with safety, danger, and risk.
2. It is important to be aware of HSS limitations when designing tasks or systems, particularly when these involve risk.
3. We need to understand how the limitations of the HSS impact learning and error rates, which are two sides of the same coin (Chapter 5).
4. Many features of advanced technology expand upon the HSS in a great variety of ways, for example, extending human sensory capabilities, or sensing critical environmental features that are outside our sensory range (Chapter 3). Effective equipment design often relies upon a thorough understanding of the HSS.

* Numerous websites provide information on human brain structures, from the very basic (News Medical, 2000–2015), to the comprehensive (Johnson & Becker, 1995–1999).

5. The HSS and its correlates provide the basis for considering more applied topics, for example, attention is a key component of consciousness (Chapter 2), and is also critical to risk perception (Chapter 4) and situation awareness (Chapter 5), as well as to error detection and avoidance (Chapter 5).

Recognizing increasing globalization, not just of business organizations, but of most aspects of our contemporary lives, wherever possible this edition attempts to present a broad perspective in portraying safety and risk issues. Events in one country or location typically affect people in many other places, and the speed of transmission via modern media can make information globally available almost instantaneously. That cultural differences exist in how safety, health, and risk issues are addressed is not a new discovery. Different jurisdictions may have quite distinct local priorities based on their level of economic and scientific development. However, as we increasingly witness global effects from issues such as climate change, habitat loss, species extinctions, environmental degradation, water harvesting, and exploiting natural resources to the point where recovery is all but impossible, what happens in one location is increasingly likely to affect the lives of millions, if not billions of us.

As the nature of work changes radically from that known by previous generations, greater flexibility required in nearly all jobs and professions means that workplaces are less likely than before to be based in a particular geographical location. As the interfaces between work, domestic, and social lives become increasingly blurred, the multiple ways in which each area of people's lives interact are more evident. For example, whether an instance of ill-health or a serious personal injury occurs during work time, or arises from domestic activities, or results from a commuting or other road traffic incident, may be irrelevant to the immediate outcome of a work absence. However, managing employees' safety and health beyond the workplace is a challenge that many organizations have yet to address. Similarly, stress arising from any combination of work or domestic factors is highly likely to spill over into other life domains. For example, long-term shiftwork affects family life as well as shortening life expectancy. The generic nature of ill-health means that morbidity from lifestyle choices, such as diet, exercise, and smoking, also affects work productivity and absenteeism. These issues are beginning to be recognized by many organizations as relevant to their operational efficiency and effectiveness. While workplace behaviors are regulated by various rules and policies, interactions with other aspects of people's lives cannot be ignored.

Responding to another reviewer's comment on the first edition, we also try in this third edition to represent the upside as well as the downside of risk. The biggest risk, for individuals and organizations, is sometimes to take no risks at all. The year that the second edition of our book appeared also witnessed the publication of the first edition of the World Economic Forum's (WEF) report on global risks, which has appeared every year since 2006. This report appeared as a harbinger of how risks were rapidly becoming more global, diversified, and interconnected, which is a feature reflected in the current edition of our book, particularly in Chapter 11, in which we address some of the key risks described in the 2014 issue of the WEF report.

Reflecting the previous discussion, like symphonic movements, the chapters in this book keep returning to three key themes. First, is the neural substrate underlying behaviors with respect to safety and risk, and their associated cognitions and emotions. As observed by Maidhof (2013, p. 2), "… neural correlates of errors can provide insights into the mechanisms of human action monitoring during a complex multimodal task … and error processing in general." The burgeoning of neuroscience research in last 25 years has effectively added another layer of understanding to a wide range of behaviors, cognitions, and emotions. While not without its methodological and analytical shortcomings (Horvath, Forte, & Carter, 2015; Kriegeskorte, Simmons, Bellgowan, & Baker, 2009; Sirotin & Das, 2009; Vul, Harris, Winkielman, & Pashler, 2009), neuroscience has made considerable contributions to our understanding of human behavior with respect to safety and risk. These contributions are particularly evident in the material comprising Chapters 2, 4, and 5.

Second, like that of all living things, humans' evolutionary history underpins all aspects of our behavior. The collective genotype has bequeathed each of us with an indelible legacy that affects all our behavior. While this inheritance is overlayed with the effects of multiple cultural traditions and varied socialization practices, underneath this veneer, individuals' motives, emotions, and cognitions cannot escape the imperatives dictated by our lengthy heritage. Evolutionary explanations are increasingly recognized as being able to account for many aspects of observed behavior (Stephen, Mahmut, Case, Fitness, & Stevenson, 2014).

Third, organizational complexity increasingly influences many aspects of human behavior. Organizations only began to supplant humans' small-group social functioning from around 8000 years ago—approximately since the dawn of agriculture—when our ancestors' nomadic lifestyle was gradually replaced by a more location-focused existence, which has since become the norm throughout most of the modern world. Relatively fixed-location societies required increased organization into larger units, leading to our highly complex contemporary governmental and commercial organizational structures. Some of the safety and risk issues that this organizational complexity has brought about are explored in Chapters 6 through 11.

chapter two

Sensing danger

Sensation describes the physiology of receiving and transmitting information from stimuli, while perception comprises the cognitive interpretation of that information. While they are distinct processes, to our conscious awareness, sensation and perception may appear as a seamless continuum. Therefore, we may rarely be consciously aware of transitioning between the contiguous processes of sensation and perception. Evolution has equipped each living organism with a sensory system to match its life requirements, particularly its survival needs, with its environment. This chapter explores humans' complex sensory system and evaluates the extent to which it can identify the main threats that we encounter in our contemporary world.

Evolution has primed us, on the one hand, to respond to opportunities presented by the environment (to eat, have sex, etc.) and, on the other, to react to environmental threats that could harm us. Until we reached the apex of the food chain, primary threats were likely to have included starvation and being attacked by animals or other humans. In the contemporary world, attack threats remain to a greater or lesser extent, while for a proportion of the world's population starvation also persists. Whatever our current circumstances, we largely retain our evolved physiological mechanisms for detecting and recognizing environmental threats and opportunities. As well as substantially modifying many of our perceptions, our current social and cultural landscape have vastly extended the range and nature of threats (and opportunities) that we currently face so that in many cases they are very different from those we evolved to confront and manage.

2.1 Operation of the senses

A sense can be conceived of as any neurologically and/or physiologically represented modality receptive to either external or internal stimuli, and on which individuals differ. Typically, senses arise prenatally and continue to develop throughout childhood and adolescence, before functionally declining at various rates during the adult lifespan (Bremner, Lewkowicz, & Spence, 2012). While they can be either partially or completely destroyed—for example, through inherited conditions, aging, trauma, infection/disease, poor nutrition, or toxic exposure—human senses can also be enhanced, either biologically—for example, by training—or by prosthetic mechanisms (e.g., glasses), or by extension (e.g., virtual reality experiences). Senses can also be manipulated, for example, by certain drugs, or in illusions (e.g., visual, or the multisensory rubber hand illusion, to which a simulated threat can be interpreted as if it were painful), or confused by cross-modal sensory presentations.* While vision is generally regarded as the most dominant sense, under some conditions, olfaction (smell) and other senses can modulate visual sensations due to neuroanatomical convergence between visual, olfactory, and other sensory regions (Haase, Cerf-Ducastel, & Murphy, 2009; Zhou, Jiang, He, & Chen, 2010). The brain's plasticity allows for functional substitution if a sense is partially or completely lost.

* For example, the well-documented phenomenon of a wine expert being fooled by a red dye added to a white wine and believing it to be red wine (see p. 76 of the second edition of *Human Safety and Risk Management*).

While we are unaware of this process, our brain continually extracts information from the external environment and from our own bodies to create a notion of where we are in relation to the outside world, thereby constructing our personal "reality" from moment to moment, including our sense of self or identity. In a myriad of possible combinations, our various senses are the channels through which this information passes, operating the whole time that we are awake. Memory and learning are also critical to sensory experience. Sensations can arrive either when we are expecting them, that is, when we are attentive—as when driving a vehicle or engaging in some other skilled performance—or they can arrive while a modality is in a preconscious state, for example, when we are startled by an unexpected stimulus such as a loud noise. Also, critical to sensory experience is temporary adaptation (reduced sensitivity), which prevents us from becoming overwhelmed with sensory information that would otherwise render us incapable of action. Habituation represents reduced interest in, or reaction to, a constant stimulus. Facilitation is an increased response to a stimulus resulting from prior exposure to another stimulus. Stimuli may also be characterized by novelty or contrast effects. Time-based measures of responses to stimuli include response latency and reaction time (RT). Reaction time for touch is 155 ms, which decreases from infancy to the late 20s, increases slightly until the 50s and 60s, and increases faster in the 70s (Mateevitsi, Haggadone, Leigh, Kunzer, & Kenyon, 2013).

Notwithstanding the continuing debate on how many senses humans have (Basbaum et al., 2008; Calvert, Spence, & Stein, 2004; Gordon, 2012; Macpherson, 2010; Nudds, 2004), our sensory modalities combine to generate our view of the world and alert us to potential dangers in our environment. Therefore, with mounting evidence that key features of the human sensory system include multisensory integration (MI), plasticity, and redundancy (Rosenblum & Gordon, 2012), it is more apposite to consider the complex interlinking of our senses as an integrated system. In this chapter, the role of six major sensory subsystems (chemosensory, tactile, somatosensory, proprioception/vestibular, audioception, opthalmoception) in sensing danger will be considered. In addition, sensory experiences will be considered as aspects of consciousness and associated cognitive attributes (e.g., awareness, attention, memory, learning).

Examples of multisensory adaptation include that olfaction, vision, and audition may be recruited in locating an important stimulus such as food (Frasnelli, Hummel, Berg, Huang, & Doty, 2011), leading Rosenblum and Gordon (2012) to suggest an evolutionary survival rationale for not leaving such key tasks to a single sensory modality. Because of our recruitment of higher cortical processes in sensing stimuli, there is no one-to-one correspondence between numbers of receptor genes, or their anatomical representation, and humans' sensory ability (Shepherd, 2004). Consciousness's location at the center of the sensory system is indicative of a cognitive (and emotive) focus for integrating all forms of sensory information, whether this is preattentive (e.g., unexpected) or predicted (subject to attention and awareness). The thalamus is the route for sensory information to and from the neocortex, and it also plays a key role in mediating selective attention (Tham, Stevenson, & Miller, 2011), as well as in reward value associated with the activation of various sensations (Haase et al., 2009).

Advances in brain scanning, functional interference, and neuroimaging techniques since the advent of electroencephalography (EEG) and event-related potentials (ERPs) include positron emission tomography (PET), repetitive transcranial magnetic stimulation (rTMS), magnetoencephalography (MEG), voxel-based morphometry (VBM), diffusion tensor imaging (DTI), functional magnetic resonance imaging (fMRI), and most recently, functional near-infrared spectroscopy (fNIRS). These techniques, as well as generation of a complete 3D map of a human brain (Amunts et al., 2013), have allowed for increasingly detailed representation of sensory and other human experiences at a neural level within the central nervous system (CNS). However, while thousands of publications have described the operation of the senses and their neurological representation in considerable detail, virtually nothing has been written on a key purpose of the senses, that is, to detect the potential for harm from environmental agents. For example, none of the 54 chapters in perhaps the most comprehensive compilation describing sensory processes (Calvert et al., 2004) addressed this issue, and the index made no reference to "danger," "threat," "harm," "risk," or "stress" within the 880 pages of text, while there was a single reference to fearful facial expressions. Not quite the same might be said of Gazzaniga's (2000) 1363-page second edition of *The New Cognitive Neurosciences*, as the 50-page index (~5700 entries) included 5 relating to "danger" from Stein, Wallace, and Stanford (2000) contribution; 34 mentioned fear, while "stress" received 12, and "post-traumatic stress disorder (PTSD)" a further 19 mentions, with "traumatic memory retrieval" also cited.

The scientific tradition of studying the senses frequently involves experimental techniques, often on animals, many of whose sensory mechanisms are very different from those of humans' (Calvert et al., 2004; Hughes, 1999). Reflecting their evolutionary heritage, other animals show great variety in the range and sensitivity of their various senses (e.g., sharks and eels can detect electric fields). However, some senses that humans do not (normally) use can be acquired or enhanced with training and practice. The tables in this chapter identify the main human senses under broad headings and what threats each may be capable of identifying. The sections that follow provide more detailed descriptions of the human senses, including how they combine to generate a picture of the world from which we can perceive threats and opportunities, which are key motivations for our behavior.

2.2 Chemical senses

The gustatory (taste), olfaction (smell), and trigeminal (irritant) sensations are collectively referred to as the chemical senses (Hayashida, Gonzalez, & Kondo, 2006; Lundström, Gordon, Wise, & Frasnelli, 2012; Organization for Human Brain Mapping, 2009). Flavor has been described as a perceptual combination of gustatory, olfactory, trigeminal, and tactile sensations, with the possible involvement of vision and audition (Auvray & Spence, 2008). Integrating olfaction, gustation, touch, and vision, as well as motor function (jaw, tongue, and pharynx), the highly individual (Hummel, Springborn, Croy, Kaiser, & Lötsch, 2011) multisensory flavor experience occurs in the neocortex (Shepherd, 2005).

Olfaction and taste are the first senses to become functional in the human newborn (Rivelin & Gravelle, 1984). While there is evidence for the processing of these sensations by partly overlapping neural mechanisms (Lundström, Boesveldt, & Albrecht, 2011) and through daily experience of flavors from food and beverages, finding evidence for a general sensitivity factor between individuals has so far been inconclusive (Hummel et al., 2011; Lundström et al., 2012). However, cortical gustatory and olfaction sensors have been found to be commonly affected in Parkinson's disease patients (Garcia-Esparcia et al., 2013). Table 2.1 provides further information on the threats that the chemical senses may be capable of identifying.

2.2.1 Olfaction (smell)

From an evolutionary perspective, olfaction's primary role appears to be to trigger awareness of odors that are novel or contextually unexpected (Köster, Møller, & Mojet, 2014). One theory of olfaction's role in danger perception is that unpleasant odors, which may indicate

Table 2.1 Threats Potentially Identified by the Chemosensory (Chemical) Senses

Sense	Illustrative threats identified
Olfaction (smell)	Spoiled/rotting food; (some) toxic/irritant gases; anxiety/fear (in others)
Trigeminal (irritant)	Fire/smoke (airborne irritants via trigeminal reflex); can awake from sleep via trigeminal reflex; selectively activated by CO_2; linked with processing fear and avoidance behaviors
Gustation (taste)	Potentially lethal "foods" (e.g., unripe, fermented, decomposing, poisonous), certain toxins (e.g., metallic); bitter taste receptors on tongue can produce gagging reflex; bitter taste receptors also in gastrointestinal (GI) tract (brush cells); irritant detectors in respiratory tract release acetylcholine to decrease respiratory rate

potential harm, are processed more rapidly than are pleasant odors, which are more likely to reflect safety (J. K. Olofsson, 2014). While the evidence remains equivocal, this notion has been supported by a number of studies. As odors are represented ipsilaterally, the phenomenon appears to reflect right-nostril stimulation and right-hemisphere activation for unpleasant odors. Complete adaptation of olfactory memory means that permanent awareness of odors within the complex olfactory environment may be detrimental as it could render humans less vigilant and attentive to detecting novel or changing odors that could signal danger (Köster et al., 2014). In contrast to vision, where identifying a danger source is critical when selecting an appropriate behavior (hide, attack, retreat, etc.), with olfaction the range of response behaviors is likely to be very limited (e.g., spit out food, flee) so that novelty and change detection have priory over identification (Köster et al., 2014).

Basic features of the anatomy, physiology, and operation of the olfactory system have been known for some time (e.g., Getchell & Getchell, 1991; Laing, Doty, & Briepohl, 1991; Shipley & Reyes, 1991). Ackerman (1990) *A Natural History of the Senses*, opens with the chapter on smell, which she calls "the most direct sense" and in evolutionary terms "the first sense" in that it eventually developed into the brain.* Shepherd (2004) described a possible route by which humans' sense of smell and the location of olfactory receptors evolved and its likely importance. The evolutionary role of olfaction might account for its having the greatest dispersion of all the senses within the brain, including several subcortical features (Lundström et al., 2011). The only dual sensory modality, olfaction, senses both objects in the body and in the external world (Small, Gerber, Mak, & Hummel, 2005).

Small et al. (2005) determined that while many chemosensory regions respond to odors irrespective of route, in some cases orthonasal (via the nose) and retronasal (via the mouth) olfaction activated different parts of the brain. Small et al. suggested that this diverse response accorded with whether an odorant represented food, with food odors normally being experienced both orthonasally and retronasally, whereas nonfood odors are sensed only orthonasally. Hummel, Olgun, Gerber, Huchel, and Frasnelli (2013) identified activation of different brain regions in response to pleasant (e.g., orbitofrontal cortex OFC) versus unpleasant (anterior cingulate cortex ACC) odors. These authors also reported large individual differences (IDs) in odor detection—up to four orders of magnitude. Olfactory processing can also operate subconsciously (Hummel et al., 2013).

The notion that humans do not have a well-developed sense of smell compared with some other animals has been challenged by experimental findings (e.g., our sense of smell can outperform sensitive measuring instruments such as the gas chromatograph—Laing

* This is contestable, as the autonomic (visceral) nervous system has also been accorded this honor.

et al., 1991), and in training studies (Rosenblum & Gordon, 2012). The main reason for humans' olfactory ability is the recruitment of multiple sensory modalities at a higher cortical level (Shepherd, 2004, 2005), which more than compensates for our relatively smaller number of receptors in this sense modality. Although our highly complex human olfactory system can detect and discriminate between thousands of odors, some at very low concentrations (Bensafi et al., 2004; Doty, 1991a; Shepherd, 2005), it has difficulty recognizing individual odors from mixtures (Laing, 1991; Shepherd, 2005). The limit of humans' detection of a single odor is from a mixture of no more than five different odors before competition at olfactory cell level inhibits the spatial code required for odor identification (Hummel et al., 2013). Different brain regions respond to different odor combinations. For example, while odor mixtures activated the cingulate, parietal, and superior frontal cortex to a greater degree than single compounds did, the lateral OFC was most strongly activated by binary mixtures with approximately equal concentrations, and least by single compounds, while the anterior OFC was activated by mixtures and deactivated by single compounds (Hummel et al., 2013). The cingulate cortex is critical in odor mixture processing, the left cingulate being more strongly activated in the presence of a binary mixture than with the same components singly (Hummel et al., 2013).

While various attempts to classify the human olfactory system in ways that are analogous with categorizing hues in vision and tastes in gustation have been suggested (Doty, 1991a), odor detection classification is more problematic than for these other senses. Shepherd (2004) described an "odor wheel" classifying human olfaction into four broad areas: (1) foods (beverages, plants, fruits, meats), (2) survival (bad foods, alarms, predator, prey), (3) social (territory, hierarchy, identify, maternal, mating), and (4) floral (scents). Different sniffs tune the olfactory system to different odorants, indicating that sensing is an active process, requiring attention (Bensafi et al., 2004). These authors pointed to the selective advantage in gathering information about the environment from as many different sources as possible (e.g., for sensing danger, identifying a food source, or finding a potential mate).

Early attempts at representing the olfactory sense neurologically used electro-olfactograms from the peripheral receptor cells and olfactory evoked potentials from the CNS, which are a variant of ERPs (Kobal & Hummel, 1991). ERPs are changes in electrical fields generated by cortical neurons that are associated with an event. EEGs record contemporaneous background neural activity. Using fMRI, Tham et al. (2011) showed that olfaction has a dual pathway to the neocortex, one path being a direct projection from the piriform cortex (located at the frontotemporal junction) and the other being via the mediodorsal nucleus of the thalamus.

Some otherwise odorless toxic gases are deliberately infused with detectable odors to serve as warnings. Doty (1991b) outlined some of the consequences of olfactory deficits, including those that are age-related, such as accidental gas poisonings and explosions (e.g., butane, propane). Exposure to many different chemicals (e.g., occupationally) has been associated with attenuating olfaction (Schwartz, 1991). Taste and smell dysfunction (e.g., partial or total anosmia) is quite common and can arise from a wide variety of disorders (Smith & Seiden, 1991) and exposures (Schwartz, 1991). The outcomes are often distressing for those who experience them, resulting in reduced quality of life (Bojanowski, Hummel, & Croy, 2013) as well as potentially increasing their exposure to certain dangers.

Diminished olfactory sensation, present in over half those aged 65–80 years, and in more than 75% of over-80 year olds, is associated with disproportionate numbers of elderly people who die in accidental gas poisonings and explosions (Doty & Kamath, 2014). Chemosensory dysfunction is likely to be associated with an olfaction-related hazardous event at some point in the life of a sufferer, with cooking incidents, spoiled food ingestion, and inability to detect leaking gas or fire being the main hazards encountered (Doty & Kamath, 2014). After adjusting for demographic variables, mortality risk was 36% higher for individuals scoring low on a smell test (Wilson, Yu, & Bennett, 2011).

Ackerman (1990, p. 41) described the fate of a man who lost his once highly-sensitive sense of smell due to an accident: "…his life was endangered … he had failed to detect the smell of smoke when his apartment building was on fire; he had been poisoned by food whose putrefaction he couldn't smell; he could not smell gas leaks." Rivelin and Gravelle (1984) described a similar range of dangers faced by clinic patients whose sense of smell had been lost. Frasnelli, Collignon, Voss, and Lepore (2011) reported that up to 5% of the population exhibited anosmia (loss of sense of smell), while a further 15% experienced hyposmia (reduced sense of smell). While loss of other sensory modalities (e.g., audition, vision) has been found to generate compensatory function in others, because of their tight associations (experienced as flavor), loss of olfaction is generally concomitant with reduced function in other chemical senses (Frasnelli, Collignon, et al., 2011).

There is increasing evidence for the important role of olfaction in various forms of human social communication (Semin & de Groot, 2013), for example, when odors elicited in response to environmental threats communicate fear to another individual (de Groot, Semin, and Smeets, 2014). de Groot et al. (2014) determined that, even when confronted with conflicting visual and auditory information, olfaction still elicited a dominant fear contagion response. Prehn-Kristensen et al. (2009) found that chemosensory signals activated brain areas involved in processing social emotional stimuli (e.g., anxiety in the fusiform gyrus, vermis, cerebellum), and others' emotional states (e.g., in the insula, precuneus, cingulate cortex), as well as attentional control systems (in the dorsomedial prefrontal cortex [DMPFC], thalamus), and the regulation of emotion and empathic feelings. Emotional contagion, such as adjusting to chemosensory anxiety signals, appears to be regulated by the distributed olfactory processing system, without being dependent on conscious mediation (Prehn-Kristensen et al., 2009).

2.2.2 *Trigeminal sense (irritants)*

Trigeminal sensations include burning, cooling, stinging, tingling, prickling, pressure, itching, and satiety, which are linked to nociception (pain). Trigeminal nerve stimulation determines our ability to localize which side of our nose received an odor stimulus (Frasnelli, Hummel, et al., 2011). Different odors are represented differentially by trigeminal stimulation. For example, low concentrations of menthol can generate a high level of trigeminal activity, while other odorants may need to be present in very high volumes to be localized by trigeminal stimulation (Frasnelli, Hummel, et al., 2011). Odors that stimulate both the olfactory and trigeminal senses may be better suited to serve as warnings than those that stimulate only the olfactory sense. Kobal and Hummel (1991) described chemosomatosensory evoked potentials, which result from high concentrations of substances that partly or exclusively excite the trigeminal nerve (rather than the olfactory nerve), including carbon dioxide, which is odorless. Responses to carbon dioxide (CO_2) are generated in the somatosensory cortex, while the brainstem of a sleeping individual can be awakened if the trigeminal reflex is alerted, for example, by noxious stimuli (Lawless, 1991).

Subregions of the cingulate cortex responsible for intensity coding of trigeminal stimuli are also involved in processing fear and other emotions as well as avoidance behavior (Lundström et al., 2011). These authors pointed out that the neural network involved in processing the chemical senses recruits several key cerebral areas, including those involved in emotion perception and expression, memory formation, storage and retrieval, and reward.

2.2.3 Gustation (taste)

Ackerman (1990) referred to taste as the "social sense" and the "intimate sense." Being closely aligned, gustation shares many features with olfaction. Gustation is also intimately connected with other senses as taste receptors are contiguous with thermoreceptors, mechanoreceptors, and nociceptors, so that everything that is tasted includes tactile, thermal, and chemesthetic sensations (Rudenga, Green, Nachtigal, & Small, 2010). As well as its obvious role in tasting food, gustation is also closely linked with the endocrine system, inter alia having receptors (endocrine cells) for oxytocin (Iwatsuki & Uneyama, 2012) and serotonin (Kapsimali & Barlow, 2013). Gustation is also intimately associated with aspects of the somatosensory subsystem, particularly hunger and thirst, as well as with receptors in the gastrointestinal (GI) tract and allied organs (e.g., pancreas), and with elements of the tactile sensory subsystem. It has been suggested that brush cells in the GI tract may be involved in nutrient chemosensation (Iwatsuki & Uneyama, 2012). GI tract cells, similar to taste buds, use analogous signals to provide nutritional information (e.g., bitter taste) to the vagus nerve (Cummings & Overduin, 2007; Hao, Sternini, & Raybould, 2008), which also transmits nutritional information from the GI tract to the CNS (Iwatsuki & Uneyama, 2012). Gustation also shares characteristics with the tactile sense of itch in that cells analogous with brush cells in the respiratory tract provide sensory information about irritants (Iwatsuki & Uneyama, 2012).

Several research teams (Haase et al., 2009; Iannilli, Singh, Schuster, Gerber, & Hummel, 2012; Veldhuizen et al., 2011) have reviewed evidence for gustation's neurological components, while Veldhuizen et al. (2011) described the cellular representation of taste within the brain as "distributed and sparse," compared with other sense modalities. Different tastes stimulate different brain regions (Haase et al., 2009). Using fMRI for salt and umami taste, Iannilli et al. (2012) found complex interactions between cortical and subcortical activity. These researchers determined that their data best supported a model that led from taste receptors in the left of the mouth, to the left nucleus of the solitary tract, thence to the left thalamus (posterior medial nucleus) and on to the left frontal operculum (lfO)/insula) before transmission to the ipsilateral prefrontal cortex (PFC). Ipsilateral predominance remained evident in the insular cortex and ipsilateral OFC. Iannilli et al. (2012) findings supported a primary gustatory cortex located in the lfO, and a secondary gustatory cortex located in the ipsilateral PFC.

Human taste is inherently linked to some diseases including obesity, stroke, heart disease, and diabetes (Kapsimali & Barlow, 2013). While certain types of foods were sought and ingested for their high nutritional value by our ancestors, in our contemporary world, excessive consumption of these same food types (e.g., those high in salt, sugars, and saturated fats) has led to epidemic proportions of these diseases in many countries. Sucrose's important ecological role may have resulted in the finding that sucrose produces significantly greater neural activation than do any of the other tastes, particularly during the hunger state (Haase et al., 2009). Research has revealed that obese individuals show greater activation of the gustatory cortex and other brain regions in response to anticipation and intake of food (Lundström et al., 2011). While acknowledging that the study of GI tract chemosensation is still at an early stage, Iwatsuki and Uneyama (2012) expressed optimism that better understanding of nutrient sensing could lead to applications for more effective control of food intake, as well as assisting with malnutrition.

2.3 Somatosensory senses

A somatosensory or internal sense (interoception or visceral perception) is any sense that is normally stimulated (e.g., by change) from within the body, for example, heartbeat awareness (Matthias, Schandry, Duschek, & Pollatos, 2009; Pollatos, Kirsch, & Schandry, 2005) or changes in blood pressure and heart rate (Critchley, Corfield, Chandler, Mathias, & Dolan, 2000). This contrasts with exteroceptive senses, such as sight and hearing, which detect objects and properties in the external environment. Others have blurred this distinction, for example, by suggesting that pain is analogous with exteroceptive processes except that it is oriented toward objects within the body (Auvray, Myin, & Spence, 2010). Certain somatosensory and tactile sensory experiences are closely linked with gustation. For example, food in the mouth is sensed both as taste and touch, as well as the intuitive link with hunger, and there is evidence of overlapping neural representation of these senses (Veldhuizen et al., 2011). Further evidence of a general interoceptive awareness is the association between good cardiac awareness and greater gastric function sensitivity (Herbert, Muth, Pollatos, & Herbert, 2012). The neural basis for such a generalized awareness is afferent fibers monitoring the physiological state of multiple body organs converging on the insular cortex (Herbert et al., 2012). Table 2.2 provides further information on the somatosensory senses.

Table 2.2 Threats Potentially Identified by the Somatosensory (Interoceptive) Senses

Sense	Illustrative threats identified
Hunger/satiety	Danger detected by GIS—responsible for identifying ingested toxic or pathogenic (e.g., bacterial, viral) material via immune cells, which secrete inflammatory substances (e.g., histamine)—detected by ENS, which may then trigger diarrhea and/or vomiting; excess blood ghrelin (e.g., due to genetic variant, poor diet, lack of exercise) continues to stimulate appetite, which can result in obesity; food shortages, social/political barriers to food access; excessive consumption leading to acute or chronic sickness; nausea from excess caloric intake
Thirst/satiety	Water shortages; social/political barriers to water access; dehydration
Stretch	Excessive mechanical force or pressure applied to skin, muscles, or other bodily sites
Magneto/electro-reception	Power-frequency electromagnetic field detection (e.g., high voltage power lines), increased childhood leukemia likelihood from long-term exposure; circadian biorhythm disruption associated with increased cancer risk (as with shiftwork); analgesia; large electric current (“electric shock”) results in nerve and tissue damage; electrical skin conductance can signify a range of stimuli at a nonconscious level (e.g., recognized faces, immediately prior to making a poor decision), which may be linked to reward and punishment centers (covert biasing system)
Vascular	Heartbeat detection enables recognition of response to a variety of potential threats; low BMI individuals are better able to identify heartbeat; high anxiety sensitivity individuals over-responsive to heartbeat stimuli, which can lead to panic attacks with symptoms that include dizziness, feeling faint, heart palpitations, and shortness of breath

2.3.1 Hunger, thirst, and satiety

As a basic survival mechanism, hunger has been psychologically characterized in various ways, including as a drive, and as a motivator. Consumption motivation is regulated by an integrated hypothalamic and neocortical neural network (Hallschmid, Mölle, Wagner, Fehm, & Born, 2001). Subjectively, hunger may be variously experienced as feelings of restlessness or emptiness, stomach pain, light-headedness, or anxiety (Friedman, Ulrich, & Mattes, 1999). As hunger feelings increased as a result of fasting, Friedman et al. (1999) found it more likely that in addition to the abdomen, the head, neck/chest, and limbs were reported as sites where the sensation of hunger was experienced. Hunger's mirror state, satiety, is a separate sensation, which is felt partly as a muscle stretch phenomenon, another component of the somatosensory subsystem. Thirst (and its version of satiety) can be similarly classified. Because of their association with the chemosensory subsystem, it may be arbitrary whether hunger and thirst are assigned to the somatosensory subsystem. Iwatsuki and Uneyama (2012) noted that GI tract taste-like sensors are not the exclusive preserve of sensory mechanisms affecting food intake. Neuroanatomical representations of hunger and satiety states have been found to differ between men and women, suggestive of differences in cognitive and emotional processing of hunger and satiation (Del Parigi et al., 2002).

Conflating hunger with taste, Ackerman (1990) provided an idiosyncratic account of why certain cultures or conditions may generate desires or cravings for particular foods. Subsequent neuroimaging studies have revealed the key role of the hippocampal and parahippocampal gyri in hunger and food cravings (Haase et al., 2009). The close link between physiological hunger states and taste pleasantness has been termed *allesthesia* (Haase et al., 2009). Hunger, food intake, taste, olfaction, and satiety act in a physiological feedback fashion to alert an organism when to feed and when to cease. Genetic variants have been identified as important in some individuals' raised obesity risk, leading to imbalance between levels of the hunger-inducing hormone acyl-ghrelin and the satiety hormone peptide YY3-36 that continue to stimulate reward centers that regulate appetite (Karra et al., 2013).

The amygdala appears to play an affective role between brain regions that modulate hunger, gustation, and satiety. By processing affective information that is partly influenced by physiological state, the amygdala moderates stimulation of the OFC and hypothalamus, which show complete suppression after satiety (Haase et al., 2009). Motivation and emotion are closely aligned with hunger and satiety (Haase et al., 2009). Morris and Dolan (2001) described the interplay between the amygdala and OFC regions in integrating visual (food), motivational (hunger), and cognitive (memory) processes.

Humans' gustatory ability to differentiate between nutritious and potentially toxic substances has been demonstrated to be mediated neurologically and multimodally (Rudenga et al., 2010). Vision and memory for food (via the OFC) are also important (Morris & Dolan, 2001; Teed, Knapp, Hagen, Lee, & Pardo, 2009). Rudenga et al. (2010) found that when participants tasted a potentially nutritive substance, connections between the insula and a feeding network including the hypothalamus, ventral palladium, and striatum, were greater than when tasting a potentially harmful substance. Their findings supported an integrated supramodal flavor system in the ventral insula that promotes feeding when flavors are potentially nutritive. Haase et al. (2009) revealed that hunger activated all five taste regions (sweet, bitter, salty, sour, umami) within the insula and thalamus, which are involved in taste processing, and also in the substantia nigra, which, like the nucleus accumbens (Morris & Dolan, 2001), is involved in processing reward value, inter alia, for food. Morris and Dolan (2001) suggested that hunger motivation activates both types of brain regions, such that their parallel activation represented an evolutionary mechanism to ensure that tastes are rewarding and not potentially dangerous.

Satiation signals arise from multiple GI system sites. Gastric satiation signals arise primarily from mechanical distension (stretch receptors), while those from the intestine derive primarily from chemosensory effects of food (Powley & Phillips, 2004). These authors reported that both types of negative feedback were carried by vagal afferents and acted synergistically in controlling feeding. Operating through different mechanisms, hunger and satiety senses defy simplistic categorization. Hormonal, neural, and metabolic signals are critical for maintaining energy homeostasis. The gut-hindbrain axis is the key to appetite regulation, involving gastric distention as well as peptides and hormones (e.g., ghrelin increases food intake, CCK is an intestinal satiation peptide) produced by the intestine and pancreas (Cummings & Overduin, 2007). Long-term body-weight regulation operates via adipository hormones, including leptin and insulin, which also regulate short-term food intake (Cummings & Overduin, 2007). Describing various studies linking peptides with nutritionally associated diseases, these authors noted the importance of increasing understanding of mechanisms mediating gut-peptide regulation in generating strategies for combating obesity and diabetes. However, they pointed out that redundancy in both GI and CNS pathways governing energy homeostasis posed serious challenges in designing antiobesity pharmaceuticals.

Sex differences in obesity rates could be related to differences in processing food stimuli, for example, visual imagery may be more important in processing satiation-related behavior in women, while men derive a greater hedonic reward effect associated with satiation (Del Parigi et al., 2002). Widespread use of "energy" drinks threatens to disorient relationships between thirst, hunger, eating, and drinking, for example, disrupting homeostatic associative learning, and degrading conditioned responses to energy intake (McKiernan, Houchins, & Mattes, 2008). Noting that over 60% of contemporary beverage consumption also supplied dietary energy, these authors found higher Body Mass Index (BMI) to be associated with lower proportional water consumption, while mean fluid intake from energy-yielding beverages was higher among an overweight group compared with a normal weight group.

Closely linked with hunger, de Araujo, Kringelbach, Rolls, and McGlone (2003) revealed that brain activation in response to water is similar to that evoked during stimulation of salt and sweet taste receptors. These authors described the neural feedback mechanisms between thirst sensation and reward value of tasting water. While anterior regions of the insular cortex appear to be dedicated to gustatory processing, posterior regions respond to water in the mouth when thirst is present (de Araujo et al., 2003). McKiernan et al. (2008) contrasted a clear bimodal pattern for hunger with a stronger and more stable daily pattern for thirst. Unlike eating to excess, due to efficient fluid excretion, drinking to excess posed fewer health risks (McKiernan et al., 2008). As with hunger and satiety, different brain regions are active in connection with thirst and satiety (Farrell et al., 2011), which is also associated with vasopressin (AVP) regulation. Produced by the hypothalamus neurohypophysial system, the cyclic peptide AVP plays a vital role in maintaining body fluid homeostasis (de Arruda Camargo, de Arruda Camargo, & Saad, 2007). As with hunger, visceral structures are also involved with fluid ingestion (Farrell et al., 2011). Friedman et al. (1999) reported that as with increasing degrees of hunger, increasing thirst is experienced in more and more bodily sites, although these differ from those reported for hunger sensations. There is evidence that with advancing age, reduced efficiency of the neural feedback mechanisms for thirst and fluid ingestion renders the elderly vulnerable to dehydration (McKinley et al., 2007).

2.3.2 Stretch

Mechanical muscular stimulation normally actives both skin receptors and muscle stretch receptors (Corden, Lippold, Buchanan, & Norrington, 2000). Corden et al. (2000) reported that following stimulus onset, short-latency ("M1" 33 ms) and long-latency ("M2" 53 ms) muscular stretch receptors are activated. These two components appear to have different origins as the M2 reflex component is not mediated by intramuscular stretch receptors. There is an age-related declining ratio between M1 and M2 receptors, which are also affected differentially by fatigue (Corden et al., 2000). Tension sensors in both muscle and nonmuscle cells depend upon the protein actin (Galkin, Orlova, & Egelman, 2012). It appears that mechanical tension tunes neurotransmission efficiency and memory formation (Yang, Siechen, Sung, Chiba, & Saif, 2008).

2.3.3 Visceral, vascular, and distributed components

Lamina I fibers throughout the body respond to organ and tissue changes, including mechanical and thermal damage as well as to metabolic conditions such as pH balance, osmolarity, muscle exercise, interstitial inflammatory agents, and to glucose, CO_2, and oxygen concentrations (Craig, 1996). These autonomic homeostatic system components are monitored by subcortical brain regions including the brainstem, hypothalamus, and amygdala (Craig, 1996). Pain and temperature modalities inform the CNS about the condition of all somatic tissues, including skin, muscles, joints, teeth, cornea, viscera, and urogenital system (Craig, 1996).

The amygdala is important in detecting potential danger in the external environment and for physiologically preparing an organism to confront a threat, which is also linked with anticipatory anxiety (Feinstein et al., 2013). Reporting three rare cases of individuals with bilateral amygdala damage who felt no fear to aversive stimuli, including potentially life-threatening events, Feinstein et al. (2013) found that exposure to 35% CO_2 concentration in air resulted in fear and panic attacks in all three individuals, suggesting that the amygdala is not essential to feel fear. That only 25% of a small sample of neurotypical individuals reported panic when exposed to the same stimulus, although at a lower level than the amygdala-damaged group, suggested that the amygdala could also inhibit or modulate panic behaviors. The authors surmised that for amygdala-damaged individuals, stimuli with the potential for harm were generally processed exteroceptively (e.g., through auditory or visual channels). However, the CO_2 threat resulted in a number of physiological changes, which engaged interoceptive afferent sensory pathways projecting to the brainstem, diencephalon, and insular cortex. Reporting that the amygdala-damaged individuals were surprised at their entirely novel reaction to the CO_2 stimulus and, unlike the controls, experienced no prestimulus anticipatory anxiety, the researchers surmised that this had activated a hitherto dormant sensory pathway.

Feinstein et al. (2013) pointed out that because many brain areas possess CO_2 and pH-sensitive chemoreceptors, the amygdala is not essential to registering internal threats. LeDoux (2013) confirmed the existence of alternative circuits for interpreting threats and the complexity of threat processing, explaining that feelings of fear were quite distinct from humans' threat processing mechanisms. Thus, the amygdala is not involved in all threat responses, for example, when these are well-learned, and when it is involved in threat perception, different circuits may be activated. Two fear components need to be distinguished—a conscious experience in the presence of danger, and behavioral and physiological responses elicited by threats. Thus, humans can respond to danger without feeling fear, which LeDoux suggested could best be described as "threat elicited defense responses."

Vascular interoception, specifically cardiac information that allows individuals to sense their own heartbeat, relies on two neural pathways terminating respectively in the insular cortex and the ACC, which are key nodes for interoception (Couto et al., 2013). While the precise mechanisms remain speculative, aspects of interoception have been identified as influencing high-level cognitive activity, including emotion recognition, social emotion, empathy, theory of mind, and decision making (Couto et al., 2013; Critchley et al., 2000). Being especially responsive to cardiac stimuli, high trait anxiety sensitivity individuals may be over-responsive to potential harm by interpreting heartbeat sounds as fear-relevant cues, thereby heightening their attention to threat signals (Pollock, Carter, Amir, & Marks, 2006). Anxiety states and panic attacks may be generated in such individuals' self-perpetuating overaroused interoceptive awareness "fear-of-fear" cycle (Pollock et al., 2006). Preferential implicit memory bias for threatening or fearful information in these individuals may lead to neutral or ambiguous situations being interpreted as dangerous (Pollock et al., 2006). The relevance of the social environment is exemplified by asymmetrically operating fear extinction responses, such that fear responses to in-group members are readily extinguished while those to out-groups are more resistant to extinction (Olsson, Ebert, Banaji, & Phelps, 2005).

2.4 *Proprioception (kinesthetic sense)*

Macpherson (2010) described proprioception as awareness of the position of parts of the body, including movement. Sensations that could be classified under the generic proprioception label are generally multimodal, involving visual, tactile, and perhaps auditory receptors as well as motion detectors in functional proximity (Balslev, Himmelbach, Karnath, Borchers, & Odoj, 2012; Blanchard, Roll, Roll, & Kavounoudias, 2013; Ricciardi et al., 2011). Thus, the tactile and visual senses are involved in the perception of motion and speed of a stimulus, including deceleration being more readily detected than acceleration (Ricciardi et al., 2011). Actions and movements dependent on the visuo-proprioception sensory axis, which affects spatial representation, are subject to age-related deficits (Rand, Wang, Müsseler, & Heuer, 2013), and there are also characteristic impairments during the early stages of progressive degenerative diseases, including Alzheimer's (Tippett & Sergio, 2006) and Huntington's disease (Say et al., 2011). These deficits, which are represented by compromised connectivity between frontal and parietal areas, can affect performance of a wide range of daily functions, including driving, using a computer, or climbing stairs. Table 2.3 provides further information on the proprioceptive senses.

Ricciardi et al. (2011) noted that speed-dependent adaptive mechanisms in the middle temporal complex could account for subjective velocity perception being underestimated more after accelerations than after decelerations. McKeefry, Burton, Vakrou, Barrett, and Morland (2008) reviewed evidence for the extensive network of cortical areas that are responsive to moving stimuli. Neural adaptation to a constant moving stimulus is represented as a gradual reduction in the firing rate. Hietanen, Crowder, and Ibbotson (2008) gave the example of prolonged driving at 100 km/h reducing perceived speed to 80 km/h. Somewhat paradoxically, the degraded veridical perception effect was coterminous with improved sensitivity to actual velocity changes. These authors found that motion adaptation at high speeds attenuated perceived speed, while adaptation at low speeds increased

Table 2.3 Threats Potentially Identified by the Proprioceptive (Kinesthetic) and Vestibular Senses

Sense	Illustrative threats identified
Motion perception	Potential collision with objects (NB—speed underestimated more after acceleration than after deceleration), speed perception affected by adaptation effects; conflicting sensory information can generate illusory self-motion
Equilibrioception (balance)	Disorientation, vertigo, dizziness, or other disturbances of balance can signal threat; individuals with diminished sensory integration functions more liable to fall (especially older adults) being particularly dependent on the visual sense; age-related peripheral sensory loss can lead to orientation loss; vestibular illusions (e.g., conflicting with vision)—instability, nausea (Ménière's Disease), possibility of falling, felt vibrations could presage earthquakes
g-Force	Nausea, unconsciousness when brain is starved of oxygen; Coriolis forces can evoke motion sickness; sensory and orientation illusions

perceived speed at higher speeds. They found reduced speed discriminability following adaptation to low speeds when tested at high speeds, and increased discriminability when tested at speeds at or below prior adaptation speed. In some motion sensitive neurons, absolute speed sensitivity is reduced to improve relative speed sensitivity (Hietanen et al., 2008). These authors postulated the operation of at least two differently tuned speed channels ("low-speed" channel and "high-speed" channel) in making speed judgments, by comparing the firing rate of cells in each channel.

2.4.1 Equilibrioception (balance)

Macpherson (2010) described this as an exteroceptive sense as it detects something outside the body—in this case the gravitational field, for example, with respect to movement, particularly of the head. Equilibrioception is closely linked with vision and the vestibular sense, whose receptors (semicircular canals) are located within the anatomical region of the auditory sense. The complex sense of balance or postural control, does not require conscious attention for full functionality, but is heavily reliant upon continual motor feedback for reweighting visual, somatosensory, and vestibular sensory inputs (Allison & Jeka, 2004). The vestibulo-ocular reflex (VOR) is the automatic mechanism feeding information from the vestibular system about head movements to the system controlling eye movements to enable object fixation (Cohen & Raphan, 2004). Allison and Jeka (2004) found that older adults with a history of falls were less adept than age-matched controls at functions dependent on effective sensory integration.

As well as the vestibular sense, visual, kinesthetic, and somatosensory systems contribute to our multisensory balance sense (Cohen & Raphan, 2004), in which the brain plays a critical integrative role in generating and maintaining spatial orientation (Allison & Jeka, 2004). Diseases of the vestibular system can produce disabling and frightening experiences, including dizziness, imbalance, and vertigo (Cohen & Raphan, 2004). The VOR initiates orientating and compensatory responses to angular head rotation and linear celeration to maintain gaze position (Cohen & Raphan, 2004). Virtual reality (VR) technologies are being developed to enhance humans' equilibrioception sense without falling (Pettré, Siret, Marchal, de la Rivière, & Lécuyer, 2011), as well as promising applications that can further broaden sensory experiences (Timmerer & Müller, 2010).

2.4.2 Vibration

The vibratory sense also has strong links with the tactile sensory subsystem. Although we can sense large vibrations through our vestibular sense, our sensory threshold does not enable us to sense vibrations at the low levels that many reptiles (e.g., snakes, crocodiles) or some mammals (e.g., manatees) (Gaspard et al., 2013) can. However, humans' detection of vibration has been used in building design (Han, Lee, & Moon, 2009). Some spiders can use the vibratory sense to detect danger via a tingling in the extremities (Hughes, 1999). Some animals can sense the electromagnetic disturbances that precede earthquakes, the static electricity produced making the animals' hair stand on end (Ackerman, 1990).

2.4.3 g-Force

Like most terrestrial life forms, humans have evolved to perform optimally at 1 *g*, which is normal gravitational force. Flying jet fighters can expose pilots to forces up to 9 *g*, which is the equivalent of nine times a person's body weight (Laing, 2001). High *g*-forces can induce nausea and loss of consciousness (G-LOC) as well as various illusions of vision and motion (Lackner & Dizio, 2004). At the other extreme, microgravity or zero gravity can also induce sickness. Various technologies have been developed to train pilots and astronauts to develop tolerance for different *g*-forces (Colenbrander, 1963; Laing, 2001). *g*-Forces in excess of 50, for example, as sustained in vehicle or other transport-related crashes, are highly likely to result in traumatic brain injury (TBI)* (Weaver, Sloan, Brizendine, & Bock, 2006), as well as other severe injuries. Using a logistic model, Weaver et al. (2006) determined the probabilities of TBI at different peak vehicle *g*-forces. To test concerns that *g*-forces experienced on roller coaster rides (~4–6 *g*s) might induce brain trauma, Smith and Meaney (2002) determined that this was of such a low likelihood as not to be of concern. Critical issues for head injury production are head accelerations and decelerations, specifically their magnitude, direction, and time interval for each occurrence (Smith & Meaney, 2002).

2.5 Tactile senses

As well as touch, tactile sensory experiences include pressure, temperature, joint position, muscle sense, movement, and pain, making this a multimodel sensory subsystem (Gallace, 2012; Pohl & Loke, 2012). Pohl and Loke (2012) identified three components of touch: kinesthetic (body movement), tactile, and haptic (e.g., actively exploring an object). The tactile senses appear to be represented by different patterns of electrical transmission, which define their properties. Thus, pain is represented by nerve impulses at irregular intervals, while itch is a fast regular pattern. Heat is represented by a crescendo as it increases and pressure by an initial peak, which fades as pressure eases (Ackerman, 1990). There is evidence for the contiguous processing of temperature and pain in the brain, while processing of pressure is more distinct (Craig, 1996). Tactile senses generally are often the most potent in generating danger warnings as they are the final frontier between our bodies and the outside world as well as being our last system of defense (Gallace, 2012). Perhaps for this reason, total loss of tactile sensation is rare. The tactile senses are also related to

* Bilateral diffuse axonal injury, the most common neuropathological effect of TBI, mainly affects the corpus callosum, cerebellum, and brainstem, resulting in vegetative and minimally conscious states. Nontraumatic injury (e.g., stroke), typically results in selective widespread damage to the neocortex and thalamus, probably due to these structures' oxygen requirements (Owen, 2013).

Table 2.4 Threats Potentially Identified by the Tactile Senses

Sense	Illustrative threats identified
Touch	Adaptation to touch sensation may result in loss if a stronger touch stimulus is applied (e.g., a wallet pickpocketed); higher levels of tactile comfort reduce resistance to persuasion
Nociception (pain)	Potential injury (e.g., from burning, stabbing, noxious chemicals) or disease (e.g., vascular), whole body response to severe pain—sweating, pupils dilate, blood pressure rises—analogous with fear response, accompanied by strong emotional response, can lead to hypervigilance whereby the body and the environment are continuously scanned for threats; anticipating pain motivates to reduce likelihood of engaging in potentially damaging behaviors; "second pain" draws individual's attention to injury and informs brain so that behavioral responses can limit further injury and promote recovery
Pressure	Crushing or weight effects on body
Temperature	Excess heat or cold (cold sensed over more of the body than heat); noxious cold, heat, and pungent compounds
Itch	Some noxious and puritogenic substances (e.g., capsaicin), skin conditions (e.g., dermatitis), several diseases, nonhistamine-generated itch can drive patients to suicide; some noxious irritant substances (e.g., cowhage spicules) activate every nociceptor

mechanoreceptors in muscles, tendons, and joints, as well as to some kinesthetic experiences, including sensing weight and vibration. For example, the comparative weight of everyday objects can influence judgments about many things, including other people and food preferences, without our being aware of it (Gallace, 2012; Piqueras-Fiszman & Spence, 2012). Haptics is the study of touch and the cutaneous and kinesthetic senses (e.g., vibrations), and includes feedback technology (Jacob, Winstanley, Togher, Roche, & Mooney, 2012; Zelek, Bromley, Asmar, & Thompson, 2003). Table 2.4 provides further information on the tactile senses.

2.5.1 Touch and pressure

Ackerman (1990) described touch as the "oldest sense," while Classen (2012) identified it as the "deepest sense." Having the most widely distributed receptors of any sense, touch is vital for health in humans and other animals, and is used in several forms of healing. For many species touch is a critical form of communication. Pei, Hsiao, Craig, and Bensmaia (2010) and Robinson (2010) described the coding of motion direction in the somatosensory cortex (SI).

2.5.2 Nociception (pain)

Of all our sensory experiences, pain (nociception) is the one most obviously linked with potential harm. As noted by Ackerman (1990, p. 106), "The purpose of pain is to warn the body about possible injury." From an evolutionary perspective, pain has also been described as a conscious manifestation of the preconscious evaluation of danger potential (Auvray et al., 2010). Davor (2008) noted that nociception was the response to noxious stimuli in the absence of consciousness, which is required to experience pain. Cortical processing may not be required to experience pain, which is activated by brainstem regions.

When pain functionality is disrupted, as in rare genetic disorders (Shorer, Shaco-Levy, Pinsk, Kachko, & Levy, 2013) or some diseases (e.g., leprosy) then multiple serious injuries can result from lack of attention to the body. Many researchers have identified pain as a highly subjective experience (e.g., Auvray et al., 2010; Hummel et al., 2011), while Ackerman noted that pain was moderated by culture and circumstances. For example, engagement in war and sport can moderate the immediate experience of pain (Auvray et al., 2010), while other moderators include initiation rites, distraction (e.g., meditation, shifting attention elsewhere), and whether the pain accompanies other important events as a matter of personal choice (e.g., childbirth, tattooing, piercing). Baliki, Geha, and Apkarian (2009) identified pain as an assessment of stimulus intensity, which persisted even when experimental participants were instructed not to attend to a painful stimulus.

There are substantial and consistent individual differences in the reported experience of different pain stimuli (Hummel et al., 2011), which may be assuaged by the body's natural pain killers (endorphins). These block neural messages representing pain signals; some classes of drugs (e.g., opiates) mimic this effect. Analgesics (e.g., aspirin) inhibit the flow of chemicals that stimulate pain receptors. Pain susceptibility has a strong (~50% variation in heritability) genetic component (Williams et al., 2012), and the genetic basis of the pain neural network has been revealed as having a highly conserved molecular mechanism across species (Kang et al., 2010; Neely et al., 2012). Pain is experienced emotionally as well as physically, and the same brain regions (bilateral insula, mid-ACC) are activated in response to painful stimuli for self and others—that is, pain empathy or "mirroring"—an affective dimension of pain (Baliki et al., 2009). While pain thresholds are considered to represent its sensory aspects, pain tolerances reflect its affective features (Hummel et al., 2011).

Lundström et al. (2011) considered pain along with the chemical senses (olfaction, gustation, trigeminal), suggesting close links between these sensory subsystems particularly with respect to common neural substrates. There has been a debate as to whether pain is a sensory modality separate from touch (Auvray et al., 2010; Gallace, 2012). De Araujo et al. (2003) summarized evidence for mid- and posterior insular cortical regions being activated by general visceral and homeostatic-related stimuli, including temperature, nociceptive stimuli, fasting, and isometric and dynamic exercise. For example, mean arterial pressure has been found to activate the insula (Critchley et al., 2000). Brainstem regions respond differentially to noxious stimuli, depending on whether pain was cutaneous (surface) or muscular (deep) in origin (Henderson & Macefield, 2013). However, while common neural substrates may be involved in responding to a range of stimuli, on the basis of their fMRI studies, de Araujo et al. (2003) considered it unlikely that exactly the same area of the mid insula was involved in responding to pain and to water.

While the spinal cord is vital in the transmission of pain stimuli (Nash et al., 2013), within the brain, pain is mediated by two parallel systems. The lateral system undertakes basic pain processing—evaluating and discriminating sensations, and determining stimulus quality and duration. The medial system executes higher-order cognitive processing, including emotional evaluation, and affective and motivational responses to painful stimuli, as well as helping to predict and avoid potentially noxious stimuli (Lundström et al., 2011). The insular cortex not only plays a central role in processing pain-related feelings (e.g., arousal) and mediating attention toward the pain source to raise awareness of the sensation, but also in empathy and compassion (Lundström et al., 2011). Connected to the attentional and emotional brain areas in the fronto-parietal and temporal areas, Lundström et al. (2011) suggested that the anterior insula's integrative function links information from different systems.

Pain is inevitably associated with a variety of other states, including attentional and cognitive impairment (Moriarty, McGuire, & Finn, 2011), affective—feelings about the pain, learning, and anticipatory responses (e.g., expectancies based on memory for prior experiences). This has led to the suggestion that rather than being a purely sensory experience, pain is a hard-wired perceptual process focusing on threat with a primary attentional function, which can extend to hypervigilance (Crombez, Viane, Eccleston, Devulder, & Goubert, 2013; Moriarty et al., 2011). The affective component of pain is linked with the ability to empathize with others' pain (Auvray et al., 2010).

Exploring conceptual and empirical evidence, others have suggested that pain is more appropriately represented as a motivational state (Auvray et al., 2010). The extent to which pain is reported does not necessarily correlate highly with the severity of traumatic injury or disease (Crombez et al., 2013; Roesler, Glendon, & O'Callaghan, 2013). Exploring links between pain and associated positive and negative affect (e.g., fear about pain), Crombez et al. (2013) revealed a potential vicious spiral whereby pain captured attention to elicit fearful thinking about pain. Fear of pain and (re)injury may be more disabling than pain itself, possibly leading to chronic pain symptoms (Auvray et al., 2010; Roesler et al., 2013). Positive affect, acceptance of pain, hypnosis, and alternative attentional capture (e.g., by stimuli that were novel or that occurred with temporal unpredictability) appeared to offer possible pain attenuation (Crombez et al., 2013). Biofeedback via the rostral ACC has also been found to moderate pain perception (Auvray et al., 2010).

In an exhaustive brain imaging study, Baliki et al. (2009) could identify no brain regions that uniquely related to experiencing pain. However, Hummel et al. (2011) found that while different pain stimuli were intercorrelated within individuals, these pain clusters showed no consistent differences in thresholds to other sensory stimuli, indicating that individual pain sensitivity was not generalizable to all sensory stimuli, thereby implying that pain is a distinct sense. Chronic pain, with an estimated population prevalence of almost 20% in Europe and North America (Moriarty et al., 2011; Williams et al., 2012), can lead to sensitization of the CNS, so that an otherwise ordinary touch (e.g., from a bedsheet) can become a painful experience (Bharate & Bharate, 2012).

Transient receptor potential channels have been identified as potential targets for cancer, respiratory diseases, and other painful conditions. Pain relief can be achieved by application of cold stimuli, releasing glutamate, which inhibits nerve cells that pass pain messages to the CNS (Bharate & Bharate, 2012), or by drugs that affect the operation of trigeminal sensory neurons (Pertusa, Madrid, Morenilla-Palao, Belmonte, & Viana, 2012).

2.5.3 Thermoception (heat, cold)

Firing patterns of thermoreceptor nerve endings are described by Orio et al. (2012) and by Bharate and Bharate (2012). Cold thermoreceptor neurons show spontaneous, tonic, or bursting, spike activity at neutral skin temperatures, which are accelerated by cooling and suppressed by warming. At static temperatures above around 30°C neural activity mainly comprises regularly fired single spikes, while bursting activity prevails at lower temperatures (Orio et al., 2012). Thermosensitive nerves detect either innocuous stimuli or noxious (painful) stimuli (nociceptors), either below around 15°C or above 43°C (Bharate & Bharate, 2012; Ritter et al., 2013).* Six thermosensitive ion channels, expressed in primary sensory

* Thermal nociception has been used as the basis for developing "active denial systems" involving 94 GHz radiation, which penetrates the outer layer of human skin to a depth of 0.4 mm causing intense pain by heating water in thermal receptors, but supposedly leaving no permanent tissue damage (Samsonov & Popov, 2013).

neurons and other channels, have different activation thresholds. As primary afferent Aδ fibers (cold receptors) are progressively blocked, cold sensibility is eliminated and the threshold at which a cold stimulus evokes a painful burning sensation rises from normal 15°C to as high as 24°C (Craig, 1996). Using a modified Ellermeier scale to measure pain and fMRI imaging, Ritter et al. (2013) found that different brainstem structures respond differentially to varying heat stimuli.

2.5.4 Puriception (itch)

While there is some overlap at a cellular level with nociception, itch receptors are anatomically distinct and itch-specific neural pathways have been identified (Namer & Reeh, 2013; Roberson et al., 2013; X-d. Wang et al., 2013). It has been suggested that, while itch-specific neurons exist, another route for itch to arise is from a sharp contrast between individual nociceptors firing and their neighbors remaining silent (spatial contrast theory; Namer & Reeh, 2013). Interestingly, opioid treatments for pain often cause itch (Namer & Reeh, 2013).

2.6 Audioception and vestibular senses

The anatomical proximity of organs responsible for audition and balance ensure that auditory senses are closely aligned with the equilibrioception kinesthetic sense, as well as linking with the sense of motion derived from the visual system. Although both are exteroceptive senses, vision is primarily spatial, while hearing is temporal. Table 2.5 provides further information on threats identified by the auditory and vestibular senses. Differing from the visual and somatosensory subsystems, auditory information is processed in multiple stations before reaching the cerebral cortex. As it cannot be established by the sensory epithelium or cochlear hair cells, a sound source location is computed by the CNS from the inputs of many hair cells (Recanzone, 2004).

2.6.1 Audition

The auditory system's major task is determining the auditory scene from the mass of available sounds. A critical auditory segmentation problem is distinguishing prey from predator. Processing auditory inputs (spectral frequency separation, temporal separation, harmonicity and temporal regularity, intensity profile, differing onsets and offsets,

Table 2.5 Threats Potentially Identified by the Auditory Senses

Sense	Illustrative threats identified
Audition (hearing)	Predatory sounds (e.g., growling) or heralding an approach (e.g., rustling); loudness may signal degree of threat (e.g., aggression represented by loud "music" from other parties); many warnings represented by sound; numerous adverse health effects can result from chronic (or even brief) loud noise exposure (noise "pollution"); pain from loud noises (>130 dB), progressive deafness from chronic noise exposure (>80 dB) and from aging effects
Pitch, volume, duration (rhythm), consonance/dissonance, and timbre	Dissonant sounds could represent warnings, "noise" contains many different frequencies, distinguishing different pitches could be critical in interpreting warnings
Echolocation	Avoiding obstacles that could otherwise result in harm

and common modulation) involves temporal integration that creates a stabilized auditory image to provide the CNS with information to determine the sound source (Yost, 2004). The range of human audition is from 15 to 24,000 Hz (more commonly quoted as 20–20,000 Hz), with capacity diminishing through the life cycle. Our hearing is most sensitive in the human voice range (~100–3500 Hz). It seems that while auditory stimuli are initially processed in primary auditory cortical regions, secondary regions are involved in more complex processes, such as retention (Penhune, Zatorre, & Feindel, 1999). These secondary regions send connections to the frontal cortex and hippocampus (Penhune et al., 1999).

Humans (and some other mammals) have been adaptively hardwired to interpret loud low-frequency sounds, including ULFs, as predator signals (Horowitz, 2012). A subsection of the autonomic nervous system, the enteric nervous system, provides sensory feedback from internal organs, a low-frequency nonauditory pathway that is involved in vibroacoustic pathology resulting from chronic exposure to vibration (Chapter 3 gives further details). Low-frequency stimuli can also therefore signal danger. The brain's attentional and memory circuits associate certain sound and infrasound stimuli with danger, while the brain's natural plasticity creates faster channels, enabling more rapid responses to previously encountered events (Horowitz, 2012).

Along with its neural substrate, this sense was critical for the development of human language and music. As well as enhancing speech in noise detection, musical training is associated with larger working memory (Parbery-Clark, Skoe, Lam, & Kraus, 2009), which is also critical to audition. That the number of peripheral auditory receptors in humans is not vastly greater than those in the cat and the rat suggests that our speech development had much more to do with elaboration mechanisms within the CNS (Shepherd, 2004).*

Sounds that are not tied to any particular language, such as cries or shrieks, are universal warnings. A domain of human factors involves identifying auditory warnings that can be universally understood. Humans have developed numerous technologies to enhance and use sound beyond the capacity of our own auditory sense, including sonar (echolocation), medical devices (e.g., stethoscope, heart rate monitor), microphones, radio telescopes, ultrasound imaging,† and hearing aids (Chapter 3 gives more details). Individuals suffering hearing disturbances, such as tinnitus, may show neural representations of their condition that differ from controls in nonauditory, as well as in auditory areas (Melcher, Knudson, & Levine, 2013).

2.6.2 Volume, pitch, rhythm (duration), and timbre

Amplitude variation produces volume (loudness), while frequency variation produces pitch and associated sensations (e.g., consonance, dissonance). Considering competing theories for sensing pitch—neuronal activity ("place" theory) and firing patterns ("temporal" theory)—Plack (2012) concluded that the auditory brain combines place and temporal information. The relative durations of a pattern of sounds determines its rhythm. Pitch and duration, both of which are essential for comprehending speech, music, and many environmental sounds, are processed in the same brain areas (Griffiths, Johnsrude, Dean, & Green, 1999), and both are linked to memory in the auditory cortices (Albouy et al., 2013). That pitch processing is affected by spatial gestural

* Humans' desire for extensive tonal experiences in daily life may be deduced from such behaviors as personalizing telephone ring tones, and downloading large volumes of music, even without the time to listen to all of it!

† Applied transcranial ultrasound (20 kHz to 20 MHz) can also attenuate subjective pain (Hameroff et al., 2013).

movement suggests a shared audiospatial representation of pitch within the temporal lobes (Connell, Cai, & Holler, 2013).

Extensive musical training enhances auditory processing, including for speech, with bidirectional effect (Asaridou & McQueen, 2013; Bidelman, 2013). This effect appears to operate by enhancing cortical preattentive and attentive pitch processing networks as well as improving brainstem plasticity and generally by more efficient processing of acoustic information (Asaridou & McQueen, 2013). Bidelman (2013) identified precortical structures, particularly the brainstem, as critical in processing nascent features of tonal music, including pitch, harmony, and consonance/dissonance, suggestive of innate hierarchical processing by the central auditory system. Within the context of the dual-pathway model of auditory processing, Lappe, Steinsträter, and Pantev (2013) identified distinct cortical and subcortical networks respectively activated in processing temporal/rhythmic and melodic musical content. Timbre refers to the quality or complexity of a musical or other sound. While there is no general consensus on the dimensions of timbre, Ball (2011) suggested: brightness—the strength of high overtones, attack—how the volume of each harmonic rises initially, and the loudness profile of the harmonics over time, or how they sustain and decay.

2.6.3 Echolocation

Dolphins, bats, and some birds are renowned for navigational feats using their echolocation ability. Time is also critical for effective echolocation. Blind (and sighted) humans can also develop this sense (e.g., using tongue clicks) to determine the shape, motion, location, and even identity of objects with great accuracy, allowing them to walk, ride a bicycle, or perform other complex motor tasks while avoiding obstacles (Papadopoulos, Edwards, Rowan, & Allen, 2011; Rosenblum & Gordon, 2012; Thaler, Arnott, & Goodale, 2011). This is an example of how one sensory modality may be replaced by another to perform a parallel function for certain types of activity, for example, navigating toward a goal, while avoiding contact with obstacles. Teng, Puri, and Whitney (2011) found that experienced blind echolocators could also identify objects haptically that they had previously sampled only echoically, suggesting that objects sampled by echolocation are recognizable by shape, and that this representation is available across sensory modalities.

Thaler et al. (2011) indicated that processing click echoes generated by the mouths and tongues of blind experts recruited brain regions typically devoted to processing vision and motion rather than audition. Alternatively clicks can be generated by a sensory substitution device or microphones, for example, to reveal the shape of a room (Dokmanić, Parhizkar, Walther, Lu, & Vetterli, 2013). Thaler et al. revealed the involvement of higher cognitive and executive control processes during human echolocation, and individual differences in cerebellar processing of self-generated click echoes. Investigating human echolocation information requirements such as pitch, timbre, and loudness, Schenkman and Nilsson (2011) found that pitch detection was critical for effective performance.

2.7 Vision

As noted by Ackerman (1990), humans' highly developed, stereoscopic, forward directed visual sense is that of a predator. Summary Text 2.1 outlines some implications of this critical aspect of human behavior and some consequences for managing risk in our environment, which are explored in subsequent chapters. While the eyes are the prime mechanism for light detection, we can also sense certain light wavelengths through our skin, akin

SUMMARY TEXT 2.1 Humans' Visual Sense and Predation

Humans' visual sense evolved to enable our ancestors to collaboratively hunt a wide range of prey species, many of which we continue to consume even though we now purchase most of our food. Our kinesthetic/vestibular sense of balance, including head stabilization when running (Lieberman, 2012), assisted our ancestors in persistence hunting of prey over long distances. The "runner's high" may have developed to enhance sensory experience when the prey was eventually observed (Lieberman, 2012).

Despite superficial trappings of modern "civilized" society, our predatory heritage is manifested in multiple contemporary ways. Notwithstanding humans' hunting of many species to extinction or near extinction (Bennett et al., 2002; Smith, 1975), our most favored domestic companions, dogs and cats, are also highly effective predators, continuing to exact a high toll on many other species. However, for at least several millennia, our main prey has been each other. Despite the annual toll of gun-related suicides and homicides, including occasional massacres of children (Dreier, 2013; Hemenway, 2009; Jager, 2004), a large percentage of U.S. citizens continue to uphold their legally sanctioned right (Second Amendment) to bear arms against real or imagined threats. Stereoscopic sights further extend shooters' already highly developed visual sense. Child deaths in hunter–gatherer societies are also comparatively high (Volk & Atkinson, 2013). It seems that, as a species, in certain circumstances we may be unable to resist our predatory heritage.

Further manifestations of humans' predatory nature and social responses to it are evident in wars and in preparations for war. While estimates are problematic, between 1946 and 2002, 15 wars each resulted in a mean of approximately 1 million human deaths (Lacina & Gleditsch, 2005). Many people are attracted to films or books about war. Stories about crime and its detection (perhaps analogous with detecting clues in our hunting ancestry) are also popular. Crime prevention and mitigation has become a major industry as people strive to protect themselves and their property. Detection has become a major and increasingly accepted feature of our lives. Our collective visual sense is massively extended by the deployment of surveillance cameras, estimated to be in the region of 5 million in the United Kingdom alone, representing 1 for every 14 people (Barrett, 2013*). We take particular note of media stories about events that could harm us (Davis & McLeod, 2003), which can serve as an "early warning" system for managing our personal risk. For this reason, moving images of disasters make compulsive viewing. Why else would the short sequence showing a train crash in Spain (in July 2013) that killed 79 people and injured 178 more, many seriously, be repeatedly broadcast on TV channels around the world soon after the event? Why is footage of the planes crashing into the World Trade Center in September 2001 shown over and over years after the event? It is because these sequences send clear messages of threats with the potential to harm us and we want to be informed about them.

The essence of risk management is to protect individuals, organizations, and communities from threats occasioned by our own species. Thus, our

* Barrett, D. (2013). One surveillance camera for every 11 people in Britain, says CCTV survey. *The Telegraph*, July 10, 2013. http://www.telegraph.co.uk/technology/10172298/One-surveillance-camera-for-every-11-people-in-Britainsays-CCTV-survey.html. Accessed June 24, 2015.

developing moral code gave rise to a variety of governance, and judicial systems needed to maintain social order and restraint. Because homicide, rape, violent assault, and other crimes against the person are part of our predatory heritage, we need laws and sanctions to address them. An example of attempts to discourage violent behavior is many jurisdictions' adherence to capital punishment—a form of jurisdictional predation—the use of which may extend to a range of crimes that harm others, including drug smuggling and corruption. As societies developed, more sophisticated social and financial forms of attack, including bullying, defamation, and fraud, required new laws and sanctions along with social structures to enforce them.

---

to an extra aspect of the sense of touch (Bailes & Lucas, 2013; Hoang et al., 2008). As the mechanics of vision are described in many texts (e.g., S. Winkler, 2013) only a brief outline is provided here. Table 2.6 summarizes the role of the visual system in identifying threats.

Normal visual experience comprises continuous rapid sequences of saccades (rapid eye movements) and fixations (Findlay & Gilchrist, 2012). Key to saccade generation is the superior colliculus (SC), which is closely linked with the eye muscles, and appears to operate as a salience map during motivated, selective, and visual search (Findlay & Gilchrist, 2012). In visual processing, selective attention modulates activity in the lateral geniculate nucleus (LGN) by (1) enhancing responses to attended stimuli, (2) attenuating responses to ignored stimuli, and (3) increasing baseline activity in the absence of visual stimulation (O'Connor, Fukui, Pinsk, & Kastner, 2002). The receptive and suppressive fields of the early visual system (V1) become more elaborate as messages progress from the LGN to V1 (Carandini, 2004). As well as encoding raw sensory signals, early visual areas participate in visual attention and perception. Top-down projections from prefrontal and parietal areas provide the attentional controls that modulate visual processing in early visual cortical areas (Heeger & Ress, 2004). After receiving the bulk of their information about visual images from the LGN, primary visual cortex neurons (V1)

Table 2.6 Threats Potentially Identified by the Visual Sensory System

Sense	Illustrative threats identified
Vision (including contrast sensitivity, image contrast, masking, pattern adaptation, depth)	Many possible visually identified threats from moving objects (e.g., approaching vehicles), other people (e.g., from "body language," gestures), or objects being approached; many threats identified by other senses may be supplemented by visual information; successful integration with other sensory input required for effective interpretation and action (e.g., illusion of motion from visual stream if an adjacent vehicle—car, train, etc., moves away giving the appearance of self-motion)
Color	Bright colors (e.g., plants, animals, lights) could signal poison or other danger; can reflect and influence mood
Brightness/luminance	Seasonal affective disorder from too little light in winter temperate regions and beyond

encode information about the size, orientation, direction of motion, and depth of image features (Boudreau & Ferster, 2004). Given humans' heavy reliance on their visual sense, numerous cortical regions integrate visual information from a large number of geniculate inputs. Visual attention seems to depend on the modulation of divisive suppression in higher cortical areas (Carandini, 2004).

The duplex nature of vision is reflected in dual visual cortical pathways (Goodale, 2004). The dorsal "action" stream, projecting from the visual cortex to the posterior parietal cortex, provides flexible control of action. The ventral "perceptual" stream projects from the primary visual cortex to the temporal lobe, providing a rich detailed representation of the world required for cognition. Working in concert for goal-directed behavior, the ventral stream identifies objects, and goals and plans actions via the PFC, while the dorsal stream controls actions from moment to moment, assisted by the premotor cortex, the basal ganglia, and brainstem. While different posterior parietal cortex (PPC) regions are critical for visual control of specific movements (of head, eye, reaching, grasping, etc.), different intraparietal sulcus regions specialize in different types of visuomotor transformations. Consciousness is required to mediate between visual input and resultant behavior (Goodale, 2004). The ventral visual cortex is required for visual awareness, as well as parietal and prefrontal areas, reflecting processes such as attention and working memory (Rees, 2004).

Building on their earlier work, Milner and Goodale (2008) identified two cortical visual systems serving different output requirements. These were labeled "vision for perception" (ventral stream), which focuses on central vision, and "vision for action" (dorsal stream), which focuses on peripheral vision. According to these authors, the two streams evolved because perception and action require different transformations of visual inputs. The ventral (perception) stream represents a visual scene to identify objects and their spatial relationships. Using direct retinal information, the dorsal (action) stream mediates programming and control of skilled performance, such as driving, on a moment-to-moment basis. Thus, humans' visual sense can respond very rapidly to change, being capable of processing images at 50–60 frames/s—consider the speed at which Formula One drivers' visual systems must adapt to changing scenes. This might be explained by Milner and Goodale's assertion that, unlike the perceptual stream, the "real time" action stream is not available to conscious experience.

Nunn et al. (2002) reviewed research indicating that activity in primary visual cortical areas (V1, V2) may be neither sufficient nor necessary for conscious visual experience. The link between perception and action is mediated by cognitive features such as memory and planning. Learning a skill such as driving initially relies heavily on conscious ventral stream inputs. However, as performance becomes increasingly skilled, control of automatized movements moves to dorsal stream processing (Milner & Goodale, 2008). Hesse, Lane, Aimola, and Schenk (2012) found that obstacle avoidance could involve both unconscious (dorsal) and conscious (ventral) stream visual processing.

In the retina about 80 cell types create 20 visual pathways to address different components of the visual sensory system (Dacy, 2004). Neurologically, visual attention is represented as neuronal tuning in the occipitotemporal and frontoparietal cortices (Çukur, Nishimoto, Huth, & Gallant, 2013). The visual cortex incorporates a complex map of thousands of object categories organized into semantic space, which serves as a template for everyday visual search. Tuning involves activation of some neurons and inhibiting others to progressively match attended visual stimuli (e.g., rapidly approaching vehicles or other humans) by hierarchically focusing on cortically represented objects of interest (Çukur et al., 2013). This common human neurological semantic representation for visual stimuli appears to parallel trained musicians' representation of key signatures in the auditory cortex (see Section 2.6.2), albeit at far greater complexity. Çukur et al. (2013) results suggested that more anterior brain regions, involved earlier in visual processing tasks, were primarily involved with representing attended visual stimuli, while representations in more frontal regions were more dependent upon current search tasks. Implications of these authors' findings include a highly dynamic attentional process in which visual search involves warping of the cortical semantic space such that representation of semantic categories contiguous with a target stimulus expand, while more distant regions contract.

2.7.1 Color

Languages differ widely in the number of color words (Ackerman, 1990) and in the nature of objects that are color identified. Electromagnetic waves between 380 nm (sensed as deep blue) and 760 nm (sensed as deep red) are within humans' visual spectrum. Wavelengths beyond human sensory experiences, but that can be sensed by some other creatures, are infrared (~10^5 nm, detectable by pit vipers, boid snakes, and some beetles) and ultraviolet (~250 nm, detectable by bees).*

Normal color vision arises through three classes of retinal cones, with peak sensitivities at different locations in humans' visual spectrum. Around 6% of males have a color deficiency known as *anomalous trichotomy* (red/green color blindness) in which either the long or medium cones' spectral position is displaced (Jordan et al., 2010). While Jordan et al. (2010) identified a potential genetic pathway in female mothers or daughters of anomalous trichromats for tetrachomacy—the possibility of four types of cones, which animal studies suggest could be interpreted by the visual cortex, these authors identified only a single individual who could be described as tetrachromatic. The possibility remains for discovering more tetrachromatic individuals.

Behaviorally, two distinct color vision pathways exist, the monocular isotropic pathway is best equipped for representing surface color, while the orientation-tuned, binocular pathway selects for shape and form (Gheiratmand, Meese, & Mullen, 2013). These appear to reflect earlier research into representations within the visual cortex, which revealed a segregated modular pathway signaling color but providing little information about shape or form, and one signaling color differences to define form without specifying actual colors (Gheiratmand et al., 2013).

2.8 Sensory synthesis and integration

Appropriately weighting and integrating information from different sensory channels is critical to effective functioning (Stein, Jiang, & Stanford, 2004). For example, combining sensory information, particularly from the eyes and ears, the brain rapidly determines the distance you are from danger. Experimental studies have revealed that people are particularly adept at detecting danger from certain sounds, such as footsteps from behind (Horowitz, 2012).

At a cellular level, primary cilia are critical to sensory detection, probably across the whole range of exteroceptive and interoceptive modalities (Hildebrandt, Benzing, & Katsanis, 2011; Lee & Gleeson, 2011). In a comprehensive review of MI research Calvert et al. (2004) devoted sections to perceptual consequences, speech, neural mechanisms,

* The shortest wavelengths (e.g., gamma rays 10^{-5}–10^{-3} nm; x-rays ~10^{-1} nm) require specialized equipment for their detection. Microwaves (up to ~1 m) and radio waves have longer wavelengths (Macpherson, 2010).

orientation, brain imaging, maturation, plasticity, and clinical studies. Multiple sensory inputs enhance detection, identification, orientation, and speed of reaction to events (Stein et al., 2004). Cross-modal information integrated in a hierarchical feed forward fashion means that sensory inputs and early representations are not confounded by higher-order integrative processes (Vroomen & de Gelder, 2004). Some cross-modal sensory illustrative cases are shown in Table 2.7.

Research increasingly identifies a neural network integrating sensory information from a wide variety of receptors (Calvert et al., 2004; Förster & Denzler, 2012; Haigh, Brown, Meijer, & Proulx, 2013; Pascual-Leone & Hamilton, 2001), which could be represented as the neural substrate for the whole sensory network. MI is ubiquitous across species (Wallace & Stein, 2007). Generic multisensory processing involves parietal and ventrolateral occipital areas (Jäncke, Rogenmoser, Meyer, & Elmer, 2012; Sathian, Prather, & Zhang, 2004), the OFC (Rolls, 2004), the insula (Baliki et al., 2009), the SC (Anastasio & Patton, 2004; Calvert & Lewis, 2004; Stein et al., 2000, 2004), the lateral occipital-temporal cortex (superior temporal sulcus, lateral occipital, and middle temporal areas; Beauchamp, 2005), and cortical association

Table 2.7 Threats Potentially Identified by Illustrative Cross-Modal or Multisensory Processes

Sensory process	Illustrative threats identified
Generic sensory integration	Wide variety from combined sensory inputs (e.g., audio–visual–tactile)
Vision and pain magnitude	Assessing size of objects rapidly and accurately; insular lesions lead to "abnormal" risk assessment due to diminished ability to gauge magnitudes for reward and risk
Pain, temperature, and emotional states	Generated by feelings associated with nociceptive stimuli
Skilled performance (e.g., driving, many work tasks)	Rehearsing synchronized auditory and motor movements might alert actors to anticipate possible performance threats
Pain, gustatory, and general visceral	Ingestion of certain toxins
Sense of direction	May be critical in unfamiliar environments, for example, escaping danger; multiple threats possible from confused orientation, navigational shortcomings, and confounded wayfinding
Developmental	Children <10 years vulnerable to hazards whose sensory appreciation relies upon optimal use of redundant input from multiple channels
Time	Affected by critical life events (e.g., serious illness, injury, war, poverty, severe economic/political instability); aging affects threat perception; fear and perceived threat both lead to overestimation of duration (FoF response component); subjective time slowing can occur during frightening brief, life-threatening experiences, enhancing cognitive (e.g., working memory, attentional shifting, speed, response accuracy, task decision making, clarity, and functional integration) and sensory capacity (e.g., awareness, faster shift to, and processing of, new targets) to facilitate rapid corrective emergency action

areas (Stein et al., 2004). Because of the brain's primary task orientation, multisensory neurons have multiple overlapping receptive fields (Stein et al., 2004). Different sensory experiences constantly compete for attention and awareness in cortical regions (Gallace, 2012).

Visual stimuli influence auditory perception (as in the ventriloquism effect) and auditory stimuli can influence visual perception, giving rise to illusions such as "seeing" visual stimuli that are consistent with simultaneously presented auditory stimuli (Recanzone, 2004). Feedback and feed forward projections within both multimodal and unimodal cortical networks may give rise to these perceptions. As noted by Ernst (2008), multiple senses are generally deployed to estimate properties such as object size, position, and orientation, so that for optimal utility multisensory signals typically carry redundant information. For example, while vision was traditionally considered to be the "dominant" sense, the sense carrying the most accurate and reliable information is weighted to gain attentional primacy (de Groot et al., 2014; Ernst, 2008; Gallace, 2012; Pascual-Leone & Hamilton, 2001). Effective orientation and action to undertake a task requires sensory ambiguities to be resolved by successful integration (Allison & Jeka, 2004; Pascual-Leone & Hamilton, 2001). This is why the brain will not tolerate contradictory conclusions from different sensory inputs, for example, as in geometric or movement illusions (Lackner & Dizio, 2004), which may be resolved by flipping between alternatives to identify which interpretation is most appropriate for the current task (Pascual-Leone & Hamilton, 2001). Various sensory combinations are integrated in different brain regions, particularly involving the frontal, temporal, and parietal cortices (Macaluso & Driver, 2004). Specific examples include audiovisual speech integration in the supratemporal auditory cortices (STAC), audiotactile in the secondary somatosensory cortices (SSSC) and STAC, while visuotactile integration occurs in the SSSC (Raij & Jousmäki, 2004).

An extensive review of neuroanatomical research led Craig (1996) to argue that the pain-temperature sensory network underpinned basic emotional and motivational states associated with homeostasis. While subcortical homeostatic responses are generally autonomic and unconscious, Craig argued that self-awareness, including feelings, was a product of the sensory system, which is critical to attention and decision making, and therefore to survival and quality of life.

Both direct and indirect cortical mechanisms operate during multisensory processing, the dominance of one relating to the nature of the stimuli, the task, or timing (Ward, 2013). Direct operation would involve feed forward only between unimodal sensory regions, while indirect operation would involve feed forward convergence into a common hub that then influences input regions via feedback activity. Given that multisensory appreciation of stimuli is the norm, attempting to count the number of distinct senses that humans, or any other species, possess is of questionable benefit. More useful is to consider the vast number of ways in which various sensory system components may be combined to provide a continuing rich textual experience. The number of ways in which sensory processes may be combined before being represented by neural integration is very large. The extent of sensory integration, redundancy, and neural plasticity leads to the conclusion that the brain is organized according to perceptual function rather than by sensory systems (Rosenblum & Gordon, 2012).

2.8.1 Time

At least two forms of time perception exist—the autonomous biological clock and perception of the passage of time, each being associated with different brain regions.

The suprachiasmatic nucleus (SCN) in the anterior hypothalamus controls a number of biological rhythms (Farajnia, Deboer, Rohling, Meijer, & Michel, 2014), generating an approximate 24-hour circadian rhythm in electrical activity, peaking near the middle of the day with a nadir around midnight. Sleep is controlled by an interaction between homeostatic and circadian processes with local centers in the brainstem, thalamus, and cortex. The SCN is subject to age-related changes, particularly reduced amplitude of the circadian timing signal, resulting from changes in neurotransmitter signaling, synaptic transmission, and cell physiology, mediated by oxidative stress (Farajnia et al., 2014).

At the heart of our stream of consciousness, time is connected to all sensory experiences (Arstila, 2012). Time is located in the MI section on the basis that Heron et al. (2012) identified generic nervous system components common to processing time alongside both visual and auditory stimuli. These authors maintained that, as the process that unconsciously decides how long sensory experiences last, time estimation is a core process in determining our view of our environment, as well as for executing complex tasks such as speech comprehension and motor coordination. Rapid assessment of very brief time intervals appears to be managed by a system of tuned duration-selective channels (of between 40 and 2560 ms), which are differentially activated by the relative match between stimulus activation and a channel's designated duration sensitivity (Heron et al., 2012). These authors posited a series of tuned channels capable of detecting subthreshold excitatory events linked to stimulus onset and offset. In effect, meaning attributed to stimuli is critically time-dependent. Further information on the sense of time is in Summary Text 2.2, while the phenomenon of time appearing to slow down during an emergency is described in Summary Text 2.3. While much remains to be discovered about the sense of time, its operation is distributed across several brain areas (Gavazzi, Bisio, & Pozzo, 2013).

2.8.2 Cross-modal plasticity

It has been known for some time that otherwise unused regions of the visual cortex in congenitally blind individuals are recruited for other sense modalities, particularly audition and touch, while deaf persons use their auditory cortex to process visual stimuli (Bavelier & Hirshorn, 2010). However, it seems that some regions of the visual cortex, for example, those processing color, remain specific to vision, while regions of the auditory cortex that process tone are also specific (Bavelier & Hirshorn, 2010). Other modalities exhibiting plasticity include somatosensory and extended-mind tools, such as using the fingers for counting and prosthetic devices (Couto et al., 2013). Multisensory plasticity during adulthood, such that when new skills are learned, or when new prostheses (e.g., spectacles) are used, based on prior knowledge, neural systems are capable of relatively rapid recalibration (Ernst, 2008).

Examples of human cortical plasticity occurring throughout life include

- Combined visual attention and movement leading to activation of several cortical regions, including the left superior parietal lobule, right fusiform gyrus, and left insula
- Somatosensory cortex reorganization, especially during learning tasks—e.g., playing a musical instrument enlarges the parts controlling finger movement relatively
- Enhanced tactile ability in blind people (Steven & Blakemore, 2004)

SUMMARY TEXT 2.2 Sense of Time

Subjective ("felt" or psychological) time is humans' universal ability to estimate time, with varying degrees of accuracy, without reference to external clocks, which like other senses, may be subject to various illusions (Gavazzi et al., 2013). No single sense organ measures the passage of time, which relies subjectively on evaluating changes in various sensory experiences. As well as being affected by musical tempo, time estimation has been found to be modulated by affective arousal (Droit-Volet, Ramos, Bueno, & Bigand, 2013). Like all sensory domains, the auditory subsystem is hierarchically organized with increasing time windows being processed sequentially further from the primary auditory cortex (Cope, Sedley, & Griffiths, 2011). Postulating a unified model of time perception, Teki, Grube, and Griffiths (2011) identified cerebellar and thalamocortical structures as mediating timing functions. Temporal context appears to determine which timing network subsystems are recruited for a task (Teki & Griffiths, 2012).

Described by Knight and Grabowecky (2000) as a central feature of consciousness, our sense of time refers to awareness of, and attention to, past, present, and future (imagined) events. A major feature of conscious experience, it allows us to adapt and orient ourselves in tune with our environment (Eisler, 2003) including toward any threats that may be present. Knight and Grabowecky identified humans' highly developed prefrontal cortex awareness of change and novelty as critical to our ability to mentally transpose ourselves through the time dimension. Remembering the past (as in episodic memory) and thinking about the future (as in imagination and planning events) has also been linked with brain networks supporting navigation (Buzsáki & Moser, 2013; see also Summary Text 2.4). Effective operation of these neural networks would be essential in personnel responsible for safety-critical tasks requiring rapid assessment of the current state of a dynamic system based on prior experiences, as in control room operations (e.g., for large rail networks, air traffic control, emergency services, or electricity distribution).

There is evidence for a change in the sense (perception) of time over the human life span (Eisler, 2003). Reporting that the subjective sense of future time has an essential role in human motivation, Carstensen (2006) maintained that gradually time remaining becomes a better predictor for a range of cognitive (e.g., memory, attention), emotional, and motivational (e.g., exploration, knowledge, well-being goals) variables than does chronological age. As individuals age, their sense of time increasingly focuses on perceived time remaining. For example, as we age, regulating emotions and optimizing psychological well-being become more important than do other types of goals, a feature which is also seen in the face of other threats that potentially limit future time, such as war or serious illness—that is, when the fragility of life is primed (Carstensen, 2006). Carstensen noted that our respective experiences, including chronic stress, education, relationships, and social status, placed individuals on different life trajectories that affect not only day-to-day living, but also health and longevity. Preferences have been shown to be fluid in the face of moving time horizons, for example, major changes to an individual's health status, or geographical upheaval.

Recent sensory history, or experience leading to expectation and/or adaptation, is critical to perceived event duration (Heron et al., 2012). While observing a rapidly moving stimulus can distort our sense of time (by velocity, visibility, complexity, and temporal frequency effects), humans' social and environmental interactions are generally temporally accurate (Gavazzi et al., 2013). Our sense of time appears to operate through Bayesian inference and expectations (i.e., priors, or "top-down" influence) of changes in our immediate environment, which allows for effective interactions, even in fast-moving and complex sequences (Gavazzi et al., 2013). These authors determined that temporal mechanisms analyzing visual motion critically exploited motor knowledge of human actions. Gavazzi et al. (2013) found that while duration of a fast constant speed was overestimated, performance was significantly more accurate for speed changes (i.e., acceleration & deceleration). This finding links time estimation with kinesthesioception as well as velocity within the proprioception sensory subsystem (see Section 2.4). Gavazzi et al. proposed a neural mechanism that constantly calibrates time estimation using visual feedback based on known physical laws of motion.

2.8.3 Developmental aspects

MI occurs progressively from early infancy through childhood (Ernst, 2008; Rivelin & Gravelle, 1984; Stein et al., 2000). For example, Connell et al. (2013) suggested that young infants (e.g., 4 months old) could already have learned to associate pitch with spatial awareness. Changing motor capacities (e.g., crawling, walking, running, cycling) provide new sensory opportunities that require neural reorganization to master the skill and learn to avoid associated harm (Lewkowicz & Kraebel, 2004). For example, in crawling infants, the optically-based perception of self-movement (i.e., visual proprioception) crucially mediates locomotor experience and wariness of heights (Dahl et al., 2013). Before sensory integration becomes possible, the sensory subsystem required for spatial perception continuously recalibrates to incorporate maturation effects (e.g., physical height, limb/digit growth, interocular separation), which affects haptic and stereoscopic depth judgments (Gori, Del Viva, Sandini, & Burr, 2008). These authors attributed the delay in infants' acquisition of wariness of heights to the adaptive need to explore the local environment through movement, prior to becoming aware of possible harmful consequences.

Gori et al. (2008) found that the integration of visual and haptic information occurred sometime between 8 and 10 years of age. Gori et al. reported that before 8 years of age, rather than optimally integrating sensory information—as adults would do—children used one sense to calibrate the other, relying upon haptic information to judge size, and vision when judging orientation. In identifying the key role of the SC in integrating multisensory information, Wallace and Stein (2007) pointed out that the earliest-appearing SC neurons were incapable of integrating cross-modal stimuli. Experiential development based upon early encounters adapts an initially highly plastic SC to meet specific environmental demands (Wallace & Stein, 2007). These authors identified temporal synchrony of different sensory inputs as primal to MI.

Sensory modalities mature at different rates during early childhood, requiring continual neural interpretative recalibration (Bremner et al., 2012; Ernst, 2008), with complementary integrating and differentiating processes operating (Lewkowicz & Kraebel, 2004; Lickliter & Bahrick, 2004). During childhood, sensory integration is traded for plasticity (Gori et al., 2008). It has been suggested that the sensory cortex may receive both feedback and feed forward inputs from several sense modalities early in development

SUMMARY TEXT 2.3 Time's Subjective Expansion

Of the oft-cited (and well-evidenced) phenomenon of time appearing to slow down during accidents or other frightening events occurring over short time periods, Arstila (2012) identified enhanced cognitive processes distorting the relation between temporal properties of external events and internal states giving the appearance of time slowing down. As external events always occur in real time, the explanation must lie in altered internal contiguous states. As it could account for fast mechanism activation with wide-ranging effects, Arstila revealed that neurotransmitter activity could explain the phenomenon. More rapid attention shifting compared with normal gives the impression that things and events in the external world move less, while our actions are driven by faster decision making, accounting for the reported phenomenon (Arstila, 2012).

Time's subjective expansion (TSE), in which stimuli duration may be overestimated by 10%–50%, may be triggered by auditory and/or visual and perhaps other sensory mode stimuli and could be adaptive from an evolutionary perspective in providing more (subjective) time for fight/flight response. It is a special case of enhanced awareness (e.g., during certain cognitive tasks or at the start of some types of seizure), and also increases when paying attention to an activity/event (Picard & Craig, 2009; Picard & Kurth, 2014; Tse, Intriligator, Rivest, & Cavanagh, 2004). Three elements required for TSE are (1) cognitive—attention (and possibly affect), (2) physiological—neurotransmitter activity, and (3) neural—anterior insula activity sampling.

Reflecting the cognitive/affective component, brain areas modulating attention report a significant stimulus, accompanied by an emotional response (e.g., fear) if the stimulus represents a threat. The latency period required to switch to a novel task is ~120 ms, while a peak in TSE occurs ~225 ms after stimulus onset (transient attention component). A central "event counter" mechanism measuring the amount of information processed and calculating the duration of perceived events was proposed by Tse et al. (2004).

As a further clue to the operation of TSE's cognitive component, in an experimental paradigm Deary et al. (2004) used a range of presentation times randomly selected with masking between presentations. Reporting on a simple inspection task—which of two lines is longer, Deary et al. found that while judgments were at chance level for presentations at 6 ms, they were almost perfect for presentations ≥60 ms. However, participants were not conscious of accurate selection until presentations were for longer periods (reflecting preconscious processing), although the authors did not state when participants became conscious of their correct decisions (perhaps at 80–120 ms).

Deary et al. (2004) found that different brain regions were activated when discriminating clear versus degraded stimuli. A posterior network of sensory-related and associated regions (precuneus, posterior cingulate gyrus, occipital gyrus, right superior inferior, right mid-temporal gyrus) was activated for high processing demands with clearly discriminable stimuli. Anterior regions (fronto-opercular regions, intrasylvian area, medial frontal gyrus, ACC) responded to degraded stimuli. Voluntary selection of motor responses was increasingly important when stimuli were less informative—in case action was required. Activity in the anterior insula, a heteromodal region that adapts to stimulus complexity, increased with task difficulty (Deary et al., 2004).

Accounting for TSE in life-threatening situations requires a mechanism with fast activation and wide-ranging effects (Arstila, 2012). Important in regulating alertness, the locus coeruleus (LC, brainstem structure) produces the neurotransmitter norephinephrine (noradrenaline), triggering a fight/flight response with a latency of 100–150 ms with input to the whole cerebral cortex, which shifts focus to generate greater sustained attention, increased working memory, faster motor responses, and enhanced clarity of thought. Time appears to slow down during frightening events due to a discrepancy between increased LC activity in producing norephinephrine while sense of normal speed of external events adapts to prevailing conditions.

From the research described, a possible TSE mechanism may be postulated. An initial stimulus activates the visual and/or auditory system (fast action 50–60 ms), triggering a transient attentional mechanism and an emotional response (e.g., fear) if the stimulus presents a threat. This activates the LC to release norephinephrine, signaling the anterior insula to increase its sampling rate from ~120 to ~80 ms, which heightens the focus of the sustained attentional mechanism, in turn leading to an evaluation of the original stimulus.

(Bavelier & Hirshorn, 2010). As development proceeds, each sensory cortex may become dominated by one sense modality, with inputs from other senses being either partially inhibited or masked (Bavelier & Hirshorn, 2010). These authors suggested two ways in which alternative recruitment might occur. First, a "bottom-up" process assumes preexisting cortical connections across sensory channels. The second way is through top-down attentional control from multisensory areas. As these options are not mutually exclusive both may play a part (Bavelier & Hirshorn, 2010).

2.8.4 Sensory substitution

Haigh et al. (2013) suggested that multisensory redundancy, represented as neural plasticity, can help to compensate for sensory loss by enhancing function in one or more remaining senses, including use of sensory substitution devices (SSDs). For example, blind individuals' occipital cortices that would normally process visual stimuli are active during tasks such as Braille reading, auditory localization, speech comprehension, and verbal recall (Haigh et al., 2013). However, these authors also found that early use of an SSD draws primarily on the sensory modality being used rather than the one being substituted. Thus, if vision is lost, then the highest bandwidth channel of remaining senses is represented by audition.* Chebat, Rainville, Kupers, and Ptito (2007) noted that while the visual cortex of the early blind is reduced in volume, it can be recruited through training other sensory modalities, including the tactile sense via the tongue. Thus, a device that uses taste sensors to enable a blind person to "see" their immediate environment even enables a blind skilled climber to conquer a difficult mountain.

It seems that neuroplasticity is a 2-stage process, first involving rapid unmasking of existing cortical connections, followed by a slower process of making new neuronal

* While the eye can deliver in the order of 4.3×10^6 bits per second (bps), the ear's capacity is in the region of 10^4 bps, while the informational capacity of the human fingertip is around 100 bps (Haigh et al., 2013).

connections (Haigh et al., 2013). However, the extent of neuroplasticity can be gauged by findings showing that neural changes in a substituted sensory modality (e.g., touch compensating for temporary vision loss) can be detected after only a few days (Merabet et al., 2006, 2008) and that an initial rapid plasticity phase follows temporary vision loss (Merabet et al., 2006). Tactile compensation for temporary vision loss, which recruited occipital visual areas, was reversed 24 h after vision restoration (Merabet et al., 2008). It has been suggested that long-term SSD users experience a form of acquired or "synthetic" synesthesia (Proulx, 2010; Ward & Meijer, 2010). Ward and Meijer (2010) described some of the history of SSD research and development, as well as some users' experiences of SSDs.

Examining compensatory mechanisms, Frasnelli, Collignon, et al. (2011) reviewed the effects of three types of cross-modal plasticity following sensory loss: on audition and touch following blindness—in which nonvisual sensory input recruited the visually deafferated occipital cortex, of deafness on visual processing, and on remaining chemical senses after one is lost. These authors found that blind individuals recruited several occipital regions to enhance various aspects of auditory processing. Deaf individuals' enhanced visual abilities included changes in higher-level attentional peripheral processing and faster reactivity to visual stimuli (Frasnelli, Collignon, et al., 2011). Ioannides et al. (2013) revealed a fast pathway from the somatosensory cortex to occipital (visual) areas in a blind individual.

2.8.5 Cross-modal interactions create a multimodal or supramodal system

Spatial awareness appears to be a product of many components of the sensory system, including vision, touch, sound, and other modalities (Connell et al., 2013). As well as the insular cortex being identified as a key center for integrating multiple sensory inputs (Baliki et al., 2009), the medial orbitofrontal cortex (MOFC) and ventromedial prefrontal cortex (VMPFC) have been designated as connection centers for exteroceptive sensory modalities (Northoff et al., 2006).* These authors also revealed the role of subcortical structures (insula, brainstem, hypophysis, hypothalamus, periaqueductal gray, colliculi) in processing interoceptive sensory data. The MOFC and VMPFC also collate exteroceptive and interoceptive sensory stimuli (Northoff et al., 2006).

Complex synchronized motor movements, such as walking, marching, dancing, singing, and speech, also require sensory input combinations (Chen, Zatorre, & Penhune, 2006; Fries & Swihart, 1990; Penhune et al., 1999). Other supramodal abilities include locating objects in space, motion detection, and shape recognition (Bavelier & Hirshorn, 2010). Stevenson and Boakes (2004) identified implicit memory effects for encoding cross-modal odor-taste learning.

Skilled performers (e.g., musicians, athletes) may rehearse using mental kinesthetic imagery integrating motor, somatosensory, auditory, and visual aspects as well as emotional elements of performance (Lotze, 2013). Details of cortical and cerebellar activation in response to sensorimotor feedback during actual performance, as distinct from mental rehearsal, are given by Lotze (2013). Brain images of skilled performers compared with those of amateurs show that the latter need to recruit more widely distributed cortical regions for mental rehearsal, while skilled performers show more efficient recruitment of cerebellar regions (Lotze, 2013).

* A much cited cross-modal conflicted example is between vision and audition—the "McGurk effect" (McGurk & McDonald, 1976)—such that a time delay between visualized lip movements and a heard syllable results in a different syllable being "heard" (Macpherson, 2010).

2.8.6 Sense of direction

Sense of direction (SoD) is a cross-modal sense, particularly involving visual, vestibular, and kinesthetic elements. Its skill requirements include awareness, spatial memory, temporal speed and direction, and tracking to create cognitive maps. Assessment methods include tasks involving landmark identification, distance estimation, direction estimation, map sketching, and self-report (Ishikawa & Montello, 2006; Montello & Xiao, 2011). Further information on sense of direction is in Summary Text 2.4.

2.8.7 Reflexes

Contrasting with endogenous attentional processes, which are under voluntary control, exogenous, involuntary, or automatic responses capture attention by variously combined sensory inputs, particularly in response to threat. These include the startle reflex or reaction (Davis, Gendelman, Tischler, & Gendelman, 1982; Koch, 1999; Mavratzakis, Molloy, & Walla, 2013), the freezing response (reduced body sway or motion cessation, and lowered heart rate: Hagenaars, Stins, & Roelofs, 2012; Hagenaars, Roelofs, & Stins, 2013; Roelofs, Hagenaars, & Stins, 2010), and the orienting reflex (Barry, 2009; Barry, MacDonald, De Blasio, & Steiner, 2013; Bradley, 2009; Posner & DiGirolamo, 2000), which may operate in various combinations when an organism is faced with a threat. The human freeze fight/flight response sequence has been proposed as a cascade model of rapid defensive reaction to a threat (Roelofs et al., 2010). Hagenaars et al. (2013) pointed to the possibility that threat detection (e.g., via startle) may generate stages that include various combinations of freezing (or tonic immobility*), orienting, and fight or flight. Orienting can be overt or covert—the latter must be inferred by neural signals from the sense organs. Control of orienting can be top-down from within (endogenous—e.g., based on the observer's intentions or expectations), or bottom-up (exogenous—automatic from previously unattended stimuli) (R. Klein, 2004). Graziano, Gross, Taylor, and Moore (2004) described the coordinating sensorimotor pathways activated by defensive reaction to threat that could be occasioned by the startle reflex (Table 2.8).

Activated by aversive stimuli, the mammalian startle reflex is an instant processing mechanism in which memory (e.g., for previous aversive events) plays a vital anticipatory or priming role (Bradley, Lang, & Cuthbert, 1993). While it may be triggered by almost any sensory modality, it is most commonly elicited from any of auditory, visual, tactile, vestibular, or somatosensory stimuli, and has a generalized attentional or arousal effect (Filion, Dawson, & Schell, 1998). Reflex intensity can vary according to internal (e.g., emotional state, anxiety level, extent of vigilance), stimulus (e.g., loudness, unexpectedness, probability), and contextual (e.g., dangerousness, darkness, terror) factors. While the startle reflex benefits the organism, it also incurs metabolic and behavioral costs. This cost-benefit problem has been solved through functional flexibility so that psychological mechanisms sensitive to an individual's vulnerability to specific threats are modulated by threat-minimizing responses (Schaller & Neuberg, 2012). Thus, when faced with information indicating high-threat vulnerability (e.g., a warning sign) the startle reflex is stronger, and we tend to engage more strongly in threat management awareness. When denied visual information (e.g., in darkness) the acoustic startle reflex may be further enhanced due to negative affect (e.g., PTSD, fear of the dark as a child) rather than increased attention (Grillon, Pellowski,

* Distinct from the autonomic freezing response, tonic immobility is a deliberate ploy to feign death, for example, when faced with a predator, and when fight, flight or freezing options no longer increase survival likelihood (Hagenaars et al., 2012).

SUMMARY TEXT 2.4 Sense of Direction

Revealing the critical entorhinal cortical function in navigation and memory by encoding current contextual information, Jacobs, Kahana, Ekstrom, Mollison, and Fried (2010) also noted the hippocampus' role in spatial navigation and episodic memory. As well as hippocampal grid cells and place cells (Domnisoru, Kinkhabwala, & Tank, 2013), spatial navigation involves the PPC (Cohen & Andersen, 2004) and the medial entorhinal cortex (Schmidt-Hieber & Häusser, 2013). Jacobs et al. (2013) proposed a triangular coordinate system between the hippocampus, entorhinal cortex, and cingulate cortex, which continuously updates an organism's position. While topographical disorientation—a highly debilitating condition rendering a person unable to orient and navigate in an environment—is generally the result of lesions, Iaria, Bogod, Fox, and Barton (2009) described an individual with this condition who had intact sensory and intellectual function but who showed lack of activation in the hippocampal complex and the retrosplenial cortex. These authors noted the interplay of several cognitive processes in topographical orientation, including attention, memory, perception, and decision-making skills.

It has been proposed that memory and planning mechanisms have evolved from learning to navigate the physical environment such that neuronal activity underlying navigating physical and mental space are essentially the same, both navigation and declarative memory being supported by activity in the entorhinal cortex and hippocampus (Buzsáki & Moser, 2013). These authors linked the two forms of declarative memory with two key components of navigation. Semantic memory, explicitly defining living things, objects, facts and events independently of temporal context, parallels allocentric (map-based) navigation, which provides static position information. Episodic memory, required for planning actions based on subjective context-based experiences, matches path-based navigation, which integrates movement and knowledge of previous positions. Hippocampal memory formation involves storing successive independent maps to allow "remapping" between experiences and environments while minimizing interference with previously stored memories (Buzsáki & Moser, 2013).

Some animals have a highly developed sense of direction (SoD) (e.g., golden hamsters, geese, toads, spiders). Humans differ markedly in their SoD (Ishikawa & Montello, 2006), depending on their relative competence in three aspects of spatial knowledge relating to working memory: for landmarks (discrete objects/scenes), routes (landmark sequences and associated decisions), and survey (configurational, map-like knowledge) (Wen, Ishikawa, & Sato, 2011). Ishikawa and Montello (2006) identified three SoD-types: (1) a highly proficient group with good SoD after one or two exposures, (2) a poor-SoD group whose route knowledge barely improved over time, and (3) a smaller group whose route knowledge could be slightly improved with practice. Although motivational elements were excluded, these findings indicated SoD to be a generic trait-like ability rather than a trainable skill set, inconsistent with a general power law of practice (Ishikawa & Montello, 2006). Good-SoD individuals encode verbal, visual, and WM spatial components to integrate landmark and ordinal route knowledge quantitatively into a common survey reference frame (cognitive map), while poor-SoD individuals rely more on visual cues to acquire route knowledge (Ishikawa & Montello, 2006; Wen et al., 2011).

SoD components—spatial visualization, orientation, and perception, have a degree of cultural universality in wayfinding, navigational tasks, and self-reports, with consistent gender differences (Montello & Xiao, 2011). Familiarity with environment types (e.g., rural or urban) is associated with ease of using reference systems aligned with those environments, with hunter–gatherers and agriculturalists typically employing absolute reference systems (Montello & Xiao, 2011). For example, to orient themselves, Inuit hunters traditionally learn to combine wind direction, weather and snowdrift patterns, animal behavior, tidal cycles, currents, and astronomical cues. However, increased reliance on global positioning system (GPS) technology, replacing territorial understanding with map-referencing, threatens to undermine the Inuit's experientially learnt spatial orientation skills, which could result in loss of life in the event of technology failure or direction via dangerous routes (Aporta & Higgs, 2005). However, being flexible and independent of weather conditions, GPS technology can usefully augment traditional Inuit wayfinding skills, for example, during blizzards (Aporta & Higgs, 2005).

This example raises the more generic issue of the extent to which technology may initially augment, but also increasingly supplant sensory-based exteroceptive knowledge. In exploring the extent to which orientation and wayfinding in the external environment was replicated within an Internet environment, Suzuki (2012) found that while real-world SoD influenced more cognitively abstract web-based navigational skills for novice users, expert web users employed different cognitive processes from those used in real-world navigation, so that their SoD was not relevant to web-based navigation tasks (Suzuki, 2012).

Merinkangas, & Davis, 1997). These authors suggested that because darkness is potentially more dangerous than daylight for humans, as a generalized unconditioned affective response, facilitation of startle in the dark would be ecologically advantageous.

After an initial central relay in the cochlear nuclear complex, the acoustic startle reflex involves an intermediate brainstem reticular formation relay, a reticulospinal pathway, with outputs via spinal cord and brainstem motoneurons (Yeomans & Frankland, 1996). Through its activation of the sympathetic nervous system and other somatic processes, the startle or surprise reaction is akin to a stress response. Fear and other negative emotions produce potentiated startle and affective modulation of startle occurs from a few months of age. While startle inhibition has been obtained in infants, inhibitory processes are not fully developed until around 8 years of age (Filion et al., 1998). Startle eyeblink modification has been reported to index various levels of cognitive and emotional processing (Filion et al., 1998), while consuming foods that cause the body to release trace amounts of opiates that elevate mood and satisfaction, could both facilitate and inhibit startle (Walla, Richter, Färber, Leodolter, & Bauer, 2010). These authors suggested that socio-cultural factors might moderate these effects.

Behavioral inaction, popularly termed the *freezing response*, has been observed in dangerous situations from which immediate action to escape would have been the optimum survival response. Hypothesized to be a response to information overload, for example, during

Table 2.8 Threats Potentially Identified by Automatic Reflex Responses

Reflex	Illustrative threats identified
Startle	Typically triggered by sudden and intense tactile, visual, or acoustic (>75–80 dB) stimulus; serves protective function against possible injury and preparation for FoF response; removing the body from harm may be life-saving reaction to a range of dangerous events; reduced startle inhibition (i.e., raised startle facilitation) in "at-risk" populations could result from heightened vigilance, high trait fearfulness, release of stress hormones, high anxiety, emotional (e.g., PTSD) state, or some clinical conditions (e.g., phobias, schizotypal personality disorder, panic disorder, anxiety disorders, schizophrenia); attenuated startle reaction observed in criminal psychopaths, being associated with the lack of emotional modulation; in normal samples, startle inhibition at 60 ms lead interval represents preattentive automatic processing, while at 120 ms it represents a combination of automatic and controlled attentional processing
Behavioral inaction (freezing)	Frequent initial response to danger when threat is distant and fear relatively low; optimizes attentional processes to prepare organism for action; aversive life events (e.g., trauma) increase the likelihood of freezing response; freezing may be the primary defense response in trauma-related disorders (e.g., PTSD); occurs when threat is close with no obvious escape route available; however, might activate inappropriately in response to dangerous situations requiring escape for survival (e.g., plane crash); attentional focus may be on threat and affective response to it rather than determining means of escape; others may need to intervene
Orienting (OR)/reflex/reaction (also called "novelty reflex," "exploratory reflex," or "What is it?" response)	Typical response to novel, significant, surprising, unexpected, or unfamiliar stimuli, particularly if aversive; motion that generates confusing stimulus input or sickness (e.g., Coriolis forces, falling, tilting, oscillating, tumbling, rolling, rapid rotation); hypervigilance to behavioral cues; body sway changes may represent attentional orienting or risk assessment response to a novel stimulus in order to optimize risk perception (Chapter 4) and action; survival may depend on appropriate OR (e.g., cautious, defensive, fearful) prior to analysis (e.g., gathering information by visual inspection, sniffing, handling) and action
Defensive reaction	Response to a variety of threats; defensive motivation contrasts with appetitive motivation as alterative responses to stimuli that generate emotional response

an acute crisis, behavioral inaction may be a response to information overload that gives the executive function time to appraise the situation and to execute an appropriate behavioral response. The human freezing response may also operate in response to social threats (e.g., angry faces communicating dominance and inducing fear), and can be associated with some social affective disorders (e.g., PTSD, social phobia, trait anxiety; Roelofs et al., 2010).

Orienting and attentional processing are likely to be associated with general arousal, indicative of sympathetic nervous system activity, rather than being valence-specific (Hagenaars et al., 2013). The three major attributes of the orienting response are novelty, intensity, and significance (Knight & Grabowecky, 2000). The largely autonomous and sequential preliminary process theory incorporates stimulus onset, novelty, and intensity, with further processing to determine stimulus relevance to current tasks (Barry, 2009; Barry et al., 2013).

2.9 *Integrative function of social-cognitive system components*

This section considers selected higher-order sensory capabilities that are particularly finely developed in humans (see Table 2.9). Bor (2012) explained that humans' enhanced ability to combine and interpret even limited sensory stimuli, compared with those available to many other animals, was due to our greatly expanded PFC. In addition to middle prefrontal areas, Siegel (2009) identified the hippocampus (mediating memory integration), the corpus callosum (linking left and right hemispheres), and the cerebellum (integrating

Table 2.9 Threats Potentially Identified by Integrative Social-Cognitive System Processes

Sensory system	Illustrative threats identified
Consciousness	Wide variety through all sensory channels
Attention and memory	Brainstem nuclei initially code stimuli as safe/not safe; stimulus detection and discrimination (e.g., threat/no threat) can be enhanced by alerting or warning signals that a stimulus is imminent, conferring adaptive advantage; conflicting sensory information can give rise to illusory effects (e.g., ventriloquism, freezing); subcortical structures appraise meaning and motivational and emotional components (e.g., reward, affect); as people age, negative stimuli (e.g., threat information) are processed less deeply compared with positive stimuli; preference for positive information may render older people more vulnerable to attempts to take advantage (e.g., financial scams)
Self (awareness)	High interoceptive awareness (IA) individuals more quickly alerted to internal bodily states indicating acute medical condition (e.g., heart attack); IA important for social cognition, including empathy; low IA individuals more prone to some health threatening conditions and mental illness, particularly eating disorder (e.g., anorexia, bulimia, dysmorphic disorder); low IA individuals also more vulnerable to others' influence, which could increase certain social or interpersonal threats; IA popularly measured as sensitivity to own heartbeat; emotional sensitivity critical to sensing emotions in self and others, particularly those that might be associated with threat (e.g., fear, anger, surprise, disgust), each of which is processed in different neural structures
Empathy	From observing others' reactions (e.g., fearful expressions) or body language as in FoF mode, or more subtly, as in facial expressions conveying emotion; ability to accurately predict another's intentions and actions (e.g., as potential predator, prey, or mate) could be critical to an individual's survival

a range of bodily processes) as the brain's key integrating regions, while the cingulate cortex has a central role with projections from both the thalamus and higher-order (inferotemporal, polar temporolateral, lateral-parietal) cortices (Damasio, 1999). Receiving multiple sensory inputs, multilayered midbrain superior colliculi communicate the outputs to brainstem nuclei, thalamus, and cerebral cortex (Damasio, 1999).

2.9.1 Consciousness

A key focus of philosophical debate over many centuries, while consciousness now has neurophysiological explanations (Owen, 2013), a single neurological framework for consciousness has not yet emerged. Consciousness is the integrating center of humans' sensory system. Theoretical positions dominating current debate about the neurophysiological status of consciousness are summarized in Summary Text 2.5. Conscious and unconscious perceptual processes have been identified as qualitatively distinct and as leading to different consequences (Merikle & Daneman, 2000). While Merikle and Daneman (2000) found that unconscious perception led to automatic reactions, conscious perception allowed individuals to modify their reaction to a stimulus. These authors reported evidence strongly indicating that unconscious processes are important in determining cognitions, affect, and action. Bodily perception of self-consciousness involves cortical integration of both exteroceptive and interoceptive stimuli (Aspell et al., 2013). While the two are highly associated, attention is not the same as consciousness, as not everything attended to reaches awareness and conscious awareness can occur without attention (Treisman, 2004). As well as consciousness, attention and memory are vital in perceiving safety, risk, and danger precepts, as well as in managing errors. The following sections provide further information on these critical cognitive functions, while the related cognitive appreciation function of situation awareness is considered in more detail in Chapter 5.

2.9.2 Attention

Dependent on flexible and highly dynamic neuronal mechanisms (Maunsell & Ghose, 2004), attention is traditionally divided into intensity components, including alertness and vigilance, and selectivity aspects. The latter include selective (focus on particular stimuli in a complex environment) or attentional resolution (Moore, Lanagan-Leitzel, & Fine, 2008; Morillon & Barbot, 2013) and divided (ability to distribute limited resources to different information sources) attention (Matthias et al., 2009). Attentional change in the overall level of arousal, alertness, or vigilance can occur independently of how attention is allocated across space or sensory modalities. Changes in vigilance depend on different neuronal mechanisms, for example, sleep or wakefulness versus attentional changes during a challenging task (Maunsell & Ghose, 2004). Infants' ability to detect amodal stimuli (acting simultaneously on multiple senses) is fundamental to selective attention (Lickliter & Bahrick, 2004), and attention has been suggested as the prime binding factor for sensory integration (de Gelder, Vroomen, & Portois, 2004). Tasks requiring visual working memory have revealed activation of the frontoparietal network in adults as well as in 3- and 4-year-old children (Buss, Fox, Boas, & Spencer, 2013).

Operating hierarchically, attention is the active process of perceptual selection, which can be location, feature, or object based, and occur either early or late in attentional processing (Freiwald & Kanwisher, 2004). The route is from retina to thalamus (LGN) to visual cortex, then to parietal and temporal lobes. The reticular complex (thalamus) forms inhibitory

SUMMARY TEXT 2.5 Theories of Consciousness (Summary Descriptions)

Describing the *recurrent processing model*, which focuses on visual experiences, Lamme (2006) maintained that consciousness requires visual area neurons to engage in recurrent (or re-entrant or resonant) processing. Lamme proposed an empirical approach to testing the dichotomy between conscious (recurrent) and unconscious (feed forward) processes.

The *global neuronal workspace framework* (Baars, 2005; Sergent & Dehaene, 2004) proposed that consciousness' neural basis is a sudden self-amplifying process that generates a global pattern of activity throughout the brain. It involves a dynamic phase transition of a sudden "all-or-nothing" reverberating and self-sustaining assembly, which underlies the threshold of consciousness (Dehaene & Changeux, 2004). This model of consciousness is probably closest to Feinberg's (2013, 2014) hierarchically nested model of brain functioning such that lower, autonomic, and emotional processes are nested within higher, voluntary mechanisms.

Tononi's (2004) more abstract and mathematically-based *information integration theory* conceptualizes consciousness as the capacity of a system to integrate information and to differentiate between vast numbers of conscious experiences in the form of an information matrix in qualia space. This theory treats consciousness as a graded, rather than an all-or-nothing system property, including its presence in a variety of states (e.g., sleep).

In Graziano and Kastner's (2011a,b) *social awareness information model*, awareness is the perceptual reconstruction of attention. Social attention is computed from visual cues that include direction of another's gaze, facial expression, body posture, and vocalization. While consciousness and awareness comprise information and constitute a representation of attention, attention is an emergent property that is not an informational representation. From an evolutionary perspective, social perception serves the adaptive function of predicting others' behavior. The model relates strongly to other social constructs, including metacognition, social cognition, empathy, theory of mind, and the default mode network.

Consistent with William James' notion of feelings emerging from the body's sensory signals, and subsequent formulations by Singer (1998), and Damasio et al. (2000) that feelings are based on homeostatic representations of changes in the body's state, Craig's (2010) *global emotional model* sentient framework views the state of self as being continually constructed, employing a "comparative buffer" always slightly behind the latest construction, providing the basis for introspection. In postulating a functional ability to shift interconnections hierarchically within all cortical networks at each moment this approach contrasts with the global neuronal and information integration approaches. Consciousness is the representation of all possible feelings—hence the "global emotional moments" descriptor.

Also closely related to the notion of self, the *neural integration mindsight* model of consciousness, propounded by Siegel (2001, 2009, 2010) integrates neural, cognitive, emotional, developmental, and social components through consilience (independent ways of knowing). Central to this model is mindful awareness, comprising bodily regulation, balancing sympathetic and parasympathetic branches of the nervous system, empathy, attuned communication, emotional balance, fear extinction/modulation (allowing learned fears to be unlearned), response flexibility (creating space between impulse and action), insight (permitting mental time travel), moral awareness (near and extended), intuition, and reframing (ability to reflect on experiences).

The *evolutionary adaptation model*, as represented by Singer (1998), reflects the gradual evolutionary progression of consciousness from phenomenological awareness of sensations, to perceiving oneself as an active agent endowed with intention and free will. The process is driven by the highly adaptive function linking sensory experiences with programmed motor actions to develop a conscious brain that can monitor its own performance, as represented in higher-order cortical structures.

---

connections with the LGN. Top-down attentional signals modulate bottom-up processes at all processing stages, with magnitude increasing from stage to stage. Congruent with late selection, highly salient task-irrelevant stimuli may be processed to a high degree, while low-saliency stimuli may be filtered out early. Other selection factors include stimulus attributes and task requirements. Different objects are represented in different brain regions (e.g., faces in fusiform face area, places in parahippocampal place area, MT/middle superior temporal, for motion).

The visual system employs spatial attentional mechanisms at multiple sites to select relevant information at different processing stages, including visual search, automatic attention capture (bottom-up, involuntary, reflexive, rapid, more resistant to interference, dissipates quickly), post-perceptual selection, and voluntary control (top-down). Attention-capturing cues initially result in faster and more accurate responses to stimuli but at slightly longer delays responses are slower at that location due to inhibition of return, as attention appears to be inhibited from returning to the previous location. Attentional capture is enhanced by cross-modal (e.g., visual + auditory; visual + tactile) unexpected stimuli from the same location. Early phase (120–140 ms) visual + auditory attention is localized in the superior temporal cortex, while early phase (110–200 ms) visual + tactile attention is localized in the lateral occipital area. Later phase attention (140–180 ms) is localized in the ventral occipital cortex of the fusiform gyrus (Hopfinger, Luck, & Hillyard, 2004).

Lateral areas of the frontal lobes are involved in adaptive control of cognition, including attention (Beer, Shimamura, & Knight, 2004). The PFC is involved in both excitatory (e.g., directing attention to relevant stimuli) and inhibitory (e.g., filtering out irrelevant information) control mechanisms, with a bias toward novelty. The DLPFC controls visual attention by regulating the posterior association cortex through predominantly excitatory connections. The OFC is linked to regions associated with emotional and social processing, including the amygdala, ACC, SI and SII. Theories about the mechanisms involved include the somatic marker hypothesis (Damasio, 1999), which maintains that poor decision making occurs when somatic information is unavailable to guide it. The OFC (particularly right OFC) is activated in response to complex social situations and needs to activate somatic effectors in the amygdala, hypothalamus, and brainstem nuclei for rapid processing of social information for rewarding outcomes. Other theories (not mutually exclusive) include reinforcement and reversal, and dynamic filtering. The DLPFC is critical to efficient processing of information through both filtering and sustaining mechanisms, and orienting to novel stimuli (Beer et al., 2004).

Attentional control mechanisms include (1) salient sensory events (e.g., signifying new object), (2) events primed by context, (3) emotionally significant events even with low detection threshold (e.g., possible threats), and (4) endogenous control (Treisman, 2004).

Selective attention produces more activation in the globus pallidus, caudate nucleus, posterior thalamus, inferior premotor cortex, insular cortex, and lateral OFC. Divided attention produces more activity in ACC and right PFC. For concurrent tasks the DLPFC and the ACC are activated, which suggests that the DLPFC is involved in allocating attentional resources. While the further apart are the competing stimuli to be attended to the higher is the level at which attentional processing occurs, lateral connections may mediate this processing. Parallel processing streams—"what" (e.g., objects and events for conscious representation) in ventral areas, and "where" (e.g., online control of actions) in dorsal areas. Selection can occur at different levels within each pathway. Attention may operate initially at a global level before feedback activation refocuses to establish the key features of a stimulus (Treisman, 2004).

Visual attention is selective. Similar to change blindness, where we are unable to detect a change(s) in a visual scene (see Chapter 5), inattentional blindness is the inability to see without attention. This means that in order to see an object we must deploy our attention to it, suggesting that, as we do not "see" everything in our visual field, vision is an active sense (Nakayama, Maljkovic, & Kristjansson, 2004). As well as being associated with activity in extrastriate and striate visual cortices, selective attention modulates activity in the thalamic LGN (O'Connor et al., 2002).

An evolutionary basis has been postulated for preference in memory and attention for negative information, this being richer than for positive information (Carstensen, 2006), and also could signal potential threat. Attention may be cued, with evidence for all possible pair combinations of visual, auditory, and tactile stimuli, as well as for involuntary cueing (Spence & McDonald, 2004). Attentional effect is oriented toward awareness of changing stimuli (Gavazzi et al., 2013). While stimuli affecting multiple sensory modalities enhance speed and accuracy of attention (Eimer, 2004; Wallace, 2004), selective attention may fail if an individual faced with multiple sensory inputs is required to respond to only one of them (Marks, 2004)—for example, when several alarms occur conterminously.

Identifying individual differences in selected and divided attention, Matthias et al. (2009) found that the degree of perceptual awareness of bodily states (interoception) was associated with accuracy of visual stimuli processing. Specifying similar processing for interoceptive signals as for attentional stimuli, Matthias et al. identified the ability to sense interoceptive signals as an indicator of self-focused attention. Interoceptive ability is also associated with the degree of emotional arousal, with common brain structures (e.g., OFC, somatosensory cortex, amygdala, right insula), also being activated during visceral sensation (Pollatos et al., 2005).*

Social emotions (fear, disgust, embarrassment, shame, guilt) regulate behavior, which contributes to homeostasis and survival (Adolphs, 2004). Emotions emerge in parallel with feelings, physiological responses, and interactions with the environment. Multilevel processes operate in self-regulation (Adolphs, 2004). Subliminal processing of fear facial expressions can be very rapid via the amygdala, SC, and pulvinar thalamus. As well as the amygdala, perception of faces is moderated by attention and involves the fusiform gyrus, dorsal and ventral visual streams, superior temporal gyrus, and other occipitotemporal cortical regions. Detailed construction of a face occurs from 170 ms, but rapid coarse processing can occur at shorter latencies (see Chapter 5). Self-modeling involves the amygdala, parietal lobe, and insula, areas that are also critical in feeling emotions (Adolphs, 2004).

* Neurological findings on visceral arousal being a prerequisite for emotional experience are consistent with the James-Lange theory of emotion, as well as supporting Damasio (1999).

2.9.3 Memory

Located in the hippocampus (inferential memory expression) and associated medial temporal lobe structures, memory involves storage, encoding, and retrieval. Different forms identified include working memory (WM) involving frontal, posterior parietal (spatial encoding), or temporal (object information) areas and long-term memory (LTM). LTM includes explicit/declarative (for experiences, facts—hippocampus, diencephalon, medial temporal areas) versus implicit/nondeclarative (behavior/performance changes); also episodic (capacity to recall specific experiences), semantic (general body of knowledge), priming, procedural (how to do something—e.g., drive a car), recognition, conditioning, and habitual behavior.

Declarative memory (e.g., awareness of a traumatic event) is represented in the medial temporal lobe and diencephalon (e.g., thalamus). Nondeclarative memory comprises (1) procedural skills and habits (e.g., operating familiar equipment or machinery) being represented in the striatum, (2) priming and perceptual learning (e.g., behavior is triggered by a primed stimulus such as an alarm), which is represented in the neocortex, (3) simple classical conditioning—(a) emotional responses (e.g., to an object associated with pain) as represented in the amygdala and (b) skeletal responses (e.g., to a vibrating platform) represented in the cerebellum, and (4) nonassociative learning (e.g., responding to an unexpected stimulus), which is represented in various reflex pathways (Squire, Clark, & Bayley, 2004; Squire & Knowlton, 2000). Priming is reflected as nonconscious effects of previous experience (Wagner, Bunge, & Badre, 2004). Lapses or errors include forgetting and distortion.

Declarative memory representations—episodic and semantic memory as world knowledge—which can be consciously recollected, are stored in distributed areas of the cortex and integrated by the hippocampus for inferential memory expression (Eichenbaum, 2004). Semantic memories are composed of a synthesis of episodic events in relational networks. As part of autobiographical memory, episodic memory allows mental time travel to an earlier part of one's life. Operational from around 18 months, our personal experiential record, or autobiographical memory, links the core self with the autobiographical self (Damasio, 1999). As it extends and retains sensory input even after the stimulus has gone, memory thereby allows for behavior that is independent of any immediate stimuli, including thinking about future consequences of actions (Davachi, Romanski, Chafee, & Goldman-Rakic, 2004).

WM is supported by the PFC in domain-specific regions based on anatomical connections with high-order sensory association areas, leading to the notion of PFC "memory fields"—DLPFC and PPC (dorsal stream) for spatial vision and VLPFC (ventral stream) for object/face vision—which are modulated by neurotransmitter activity (e.g., dopamine, serotonin, GABA inhibitor), with corresponding auditory streams. Thus, the ventral PFC (e.g., face stimuli selectively activate inferior frontal gyrus) is engaged when someone maintains feature or object information to guide behavior. WM for object features recruits the same PFC ventral regions. The superior frontal sulcal region of the dorsal PFC is activated during maintenance of spatial information. The lateral PFC is constantly engaged when keeping verbal material in mind. The right PFC is primarily engaged when keeping visuospatial information in mind. The medial PFC is engaged when humans think about social information, including themselves (Davachi et al., 2004).

Personality trait self-knowledge is acquired through domain-specific learning mechanisms, stored in particular locations, and retrieved using specialized search engines (S. B. Klein, 2004). Semantic memory is generic and context-free and makes no reference to the self (except purely factual—e.g., where you were born). Episodic memory about the self is autobiographical and self-referential. As part of semantic memory, trait summaries are stored separately from episodic memories. Trait summaries serve a social function, allowing rapid judgments to be made about other people by referring to this memory subsystem. These are compared with episodic memories that may either confirm or contradict the trait summary about someone (including oneself). Inconsistent episodes may be primed when a trait summary is recalled. Trait-consistent episodes are primed in the absence of a trait summary. This is explained in adaptive terms to ensure that the right information mix is provided when needed for decision making or action (S. B. Klein, 2004).

Related to WM, which is multifaceted, and dependent on PFC (VLPFC, DLPFC) for guiding retrieval, cognitive control directs our thoughts and responses toward our goals (Wagner et al., 2004). Essential to planning and goal-driven behavior—including error detection and control (Chapter 5), the frontal lobes are involved in working memory, endogenous attentional control, response selection, inhibition and response monitoring, responding to affective signals, and (e.g., risk-related) rewarding/punishing stimuli (Humphreys & Samson, 2004).

2.9.4 The self and self-awareness

Self-awareness or self-knowledge is the sense of self, which is shared with some other phylogenetically higher animals. Four levels of awareness identified by Siegel (2009) were sensation, observation, conception, and knowing, which could be combined through mindful practice. Subject to individual differences, self-knowledge and body awareness integrate interoceptive awareness, for example, being able to hear one's heartbeat, with exteroceptive information, for example, seeing one's face, via the right insular lobe (Tsakiris, Tajadura-Jiménez, & Costantini, 2011). As an individual difference, interoceptive sensitivity predicts malleability of body representations, as in the rubber hand illusion (Tsakiris et al., 2011). High interoceptive awareness is positively correlated with attentional performance (Matthias et al., 2009).

Neuroscience studies linking sensing danger with aspects of the self are awaited. For example, of the 27 neuroimaging studies in Northoff et al. (2006) meta-analysis of self-referential processing, none addressed sensing of harmful stimuli, which was also the case in Legrand and Ruby (2009) meta-analysis of 79 studies. In Northoff, Qin, and Feinberg (2011) meta-analysis of 57 studies, only a study of "self-administered pain" could be considered as related to harm. However, the notion of an autobiographical self, linking past, present, and future (Northoff et al., 2011) implies memory for significant events, such as encountering harm, and drawing on such memories when sensing potentially harmful stimuli.

2.9.5 Empathy

Fundamental to human social interactions, empathy allows shared understanding of others' sensations and emotional states (Bufalari & Ionta, 2013). These authors suggested that empathy could be represented by mirrorlike mechanisms analogous with mirror neurons that encode both executed and observed actions. Bufalari and Ionta (2013) identified the insula and the ACC as key to understanding and reacting to others' feelings. O'Doherty, Rolls, and Kringelbach (2004) described the role of the amygdala and associated cortical regions (e.g., OFC) in assessing fear in others' expressions, even outside conscious awareness.

2.10 Sensing danger

Cortical and subcortical integration of sensory information is fundamental to the way in which humans and other animals experience sensations (Beauchamp, 2005). Sensory information can arrive either preattentively (e.g., loud noise, oxygen depleted atmosphere) or while an organism is attending to, or expecting a stimulus. Also critical are learning from past experiences and their representation in memory to generate an interpretive filter through which perception occurs. Areas of the brain involved in memory (e.g., hippocampus) are also part of the processing of most aspects of sensory experience. This is linked with expectation, which produces a predisposition to sense certain stimuli in particular ways. Attention is a related feature of humans' sensory experiences, although some stimuli may be sensed without attention as a prior requisite. Central to the processing of sensory information is consciousness, represented by an aware state, usually either prior to stimulus onset, but which could be evoked by certain stimuli, for example, during sleep when the trigeminal reflex is activated.

Historically, food availability was not constant, so that body fat served as a store during times of plenty and as a reserve during times of shortage (McKiernan et al., 2008). In agrarian societies, annual cycles of weight gain during harvest and weight loss during planting were associated with long-term energy balance. However, food processing and distribution networks in developed societies have secured a constant, inexpensive food supply requiring little personal energy expenditure to acquire. While the contribution of main meals to total energy requirement has remained relatively stable, these advancements have facilitated increased energy consumption, particularly in the form of snacking and "energy" drinks (McKiernan et al., 2008). Humans appear to have no innate ability to sense the danger from these changes.

2.10.1 Current threats to human health and safety

Given humans' endowment of a highly sophisticated sensory system, to what extent are we able to perceive the main threats confronting us in contemporary society? The World Health Organization (WHO) produces breakdowns of human mortality data, cross-tabulated with age group, income group, and other variables, which represent a high-level measure of the risk of dying from a particular agent at a given stage of life. A summary of some recently available data is shown in Table 2.10.

Noncommunicable diseases (NCDs) were responsible for two-thirds of the approximately 55 million deaths to people worldwide in 2011 (WHO, 2013). The four main NCDs were cardiovascular diseases (primarily ischemic heart disease and stroke), cancers,* diabetes, and chronic lung diseases. While high-income countries had the highest incidence of NCD deaths (87%) in 2011 (WHO, 2013), Alwan et al. (2010) estimated that 23.4 million deaths (64%) were due to NCDs in 23 low- and lower-middle income countries that they studied. Tobacco use and being overweight were common features, with few cost-effective interventions to reduce these risk factors (Alwan et al., 2010). Injuries (all types) resulted in 9% of all deaths (5 m) worldwide, with road traffic injuries claiming nearly 3500 lives each day in 2011 (WHO, 2013).

Cancer is the second most common cause of death in Europe (Argilés, 2005). While pain may be associated with some forms of cancer (e.g., stomach), other forms are pain free, particularly in the early stages (von Meyenfeldt, 2005). Main environmental factors

* Some 80% of cancer patients suffer from malnutrition as their metabolism speeds up, while up to 40% die of cachexia (Argilés, 2005; von Meyenfeldt, 2005).

Table 2.10 Mortality Data Related to Humans' Sensory System Detection Abilities

Adult mortality descriptor	Extent	Detection ability of human sensory system
Ischemic heart disease	Identified as primary cause of death for some years; in 2011 accounted for 12.9% of all deaths (7 m) worldwide; highest prevalence among upper-middle (17.1%) and high-income (14.1%) groups	While no human sensory mechanism is dedicated to identifying early stages of heart disease, in ischemia even a few dead heart muscle cells may activate nociceptors, so that any degree of ischemia may cause pain; nociceptors fully alerted once symptoms become serious or life-threatening
Stroke	Identified as 2nd most common cause of death for some years; in 2011 accounted for 11.4% of all deaths (6.2 m) worldwide; highest prevalence among upper-middle income group (17.9%)	No human sensory mechanism dedicated to identifying conditions prestroke (ischemic—detached blood clot lodges in brain artery, or hemorrhagic—brain artery wall ruptures); sensory system alerted once symptoms become serious or life-threatening; sensory system liable to severe morbidity, functionality rarely fully recovered
Lower respiratory infections	3rd most common cause of death for some years; in 2011 accounted for 5.9% of all deaths (3.2 m) worldwide; highest prevalence among low (10.4%) and lower-middle (7.5%) income groups	At least some symptoms likely to be detected by or affect sensory system elements—for example, chemosensory (trigeminal, gustation, olfaction), tactile (nociception, itch), and somatosensory (respiration); however, whether sensory "warnings" are heeded (e.g., by smokers) may be problematic
Chronic obstructive pulmonary disease	4th most common cause of death for some years; in 2011 accounted for 5.4% of all deaths (3 m) worldwide; highest prevalence among lower-middle (6.4%) and upper-middle (6.5%) income groups	
Diarrheal diseases	5th most common cause of death for some years; in 2011 accounted for 3.5% of all deaths (1.9 m) worldwide; highest prevalence among low (7.3%) and lower-middle (5.9%) income groups	Likely to be mainly through water-borne agents, which may/not be directly detectable by chemosensation (trigeminal, gustation, olfaction), or indirectly detectable, for example, by visual inspection of water or food quality; cramps or dull abdominal ache due to increased sensitivity of intestinal nerves (visceral hypersensitivity) occurs when the intestines are stimulated or stretched; intestinal signals sent to brain experienced as discomfort or pain, depending on the degree of stimulation

(*Continued*)

***Table 2.10* (*Continued*)** Mortality Data Related to Humans' Sensory System Detection Abilities

Adult mortality descriptor	Extent	Detection ability of human sensory system
HIV/AIDS	6th most common cause of death for some years; in 2011 accounted for 2.9% of all deaths (1.6 m) worldwide; highest prevalence among low income groups (7.4%)	Likely to be mainly through sexual contact, sharing needles, or more rarely though blood transfusion; sensory system not primed to detect presymptomatic state in sexual partner, nor potential for needlestick transmission, nor by blood transfusion
Trachea, bronchus, and lung cancers	Risen from 9th (in 2000) to seventh most common cause of death in 2011—accounted for 2.7% of all deaths (1.5 m) worldwide; highest prevalence among upper-middle (4.0%) and high income (6.%) groups	At least some symptoms may be detected by or affect sensory system elements—for example, chemosensory (trigeminal, gustation, olfaction), tactile (nociception, itch), and somatosensory (respiration); however, whether sensory "warnings" are heeded (e.g., by smokers) may be problematic
Diabetes mellitus	Risen from 10th (in 2000) to 8th most common cause of death in 2011—accounted for 2.6% of all deaths (1.4 m) worldwide; similar incidence across most income groups	No sensory system component available to detect early symptoms; later stage symptoms may particularly adversely affect visual, somatosensory, and nociception system components
Road traffic injury	Risen from 11th (in 2000) to 9th most common cause of death in 2011—accounted for 2.3% of all deaths (1.3 m) worldwide; highest prevalence in upper-middle income groups (3.1%)	All road users have some level of vulnerability, with pedestrians, cyclists, and motorcyclists at highest risk; while sensory system components (especially visual, auditory, kinesthetic, reflex) may respond sufficiently rapidly to counter threats (e.g., from other vehicles), in many cases they are incapable of sufficiently rapid response, perhaps due to pharmacological effects (e.g., alcohol, drugs) or various other factors (e.g., age-related cognitive deficits)
Malaria	Highest incidence in low-income group—4.1% of all deaths (0.3 m) in this group in 2011	Insect vector may be difficult to detect with human sensory system
Tuberculosis	Fallen from 8th (in 2000) to 13th most common cause of death in 2011—accounted for 1.8% of all deaths (1 m); highest prevalence in low (3.4%) and lower-middle (2.8%) income groups	No human sensory system element developed to detect disease vector, although already infected individuals may be identifiable by a combination of visual, auditory, and chemosensory stimuli

(*Continued*)

Table 2.10 (Continued) Mortality Data Related to Humans' Sensory System Detection Abilities

Adult mortality descriptor	Extent	Detection ability of human sensory system
Malnutrition	In 2011, accounted for 3.4% of all deaths (0.3 m) in low-income group, being the 9th most common cause of death in this group	While chemosensory and somatosensory system elements will be severely affected, socio-economic and political constraints may operate to deny basic sustenance to large numbers of people
Hypertensive heart disease	In 2011, accounted for 2.6% of all deaths (0.5 m) in upper-middle income group, and 2.4% of all deaths (0.2 m) in high income group	No human sensory mechanism dedicated to identifying early stages of heart disease; headache, blurred vision, discomfort due to external heat impression are among sensations that may be mostly ignored by individuals with such conditions; nociception system alerted once symptoms become serious or life-threatening
Liver cancer	In 2011, accounted for 2.6% of all deaths (0.5 m) in upper-middle income group	No human sensory system element developed to detect disease symptoms; later stages detected by nociception and somatosensory system elements
Stomach cancer	In 2011, accounted for 2.6% of all deaths (0.5 m) in upper-middle income group	No human sensory system element developed to detect disease symptoms; later stages detected by nociception and somatosensory system elements
Alzheimer's disease and other dementia	In 2011, accounted for 5.7% of all deaths (0.5 m) in high income group	Early symptoms detectable by central cognitive process, particularly memory function
Colon and rectal cancers	In 2011, accounted for 3.2% of all deaths (0.3 m) in high income group	Visual system may detect early symptoms (e.g., blood in stool); later stages (e.g., obstruction by larger tumor mass) likely to be detected by nociception and somatosensory system elements
Breast cancer	In 2011, accounted for 1.9% of all deaths (0.2 m) in high income group	Tactile system (touch receptors) may detect early symptoms with frequent self-examination (or accidentally, or by the significant other)

Sources: World Health Organization, Global Status Report on Non-Communicable Diseases 2010, WHO, Geneva, Switzerland, 2011; World Health Organization, The Top 10 Causes of Death, WHO, Geneva, Switzerland, 2013.

associated with cancer are cigarette smoke, UV exposure, diet, alcohol and other drugs, industrial pollutants, and ionizing radiation (von Meyenfeldt, 2005). The WHO (2013) has estimated that currently approximately 1 in every 10 deaths worldwide is attributable to smoking. Among numerous side-effects, anticancer treatments typically affect the olfactory, gustatory, and satiety senses (Argilés, 2005; von Meyenfeldt, 2005).

There are substantial differences between rich and poor countries' patterns of mortality. For example, in high-income countries 7 in every 10 deaths are to people aged 70 years and above (WHO, 2013), with a preponderance of chronic diseases (cardiovascular, chronic obstructive lung, cancers, dementia, diabetes). In low-income countries, nearly 4 in every 10 deaths are among children under 15 years (WHO, 2013). Almost one-third of deaths in low-income countries are accounted for by infectious diseases, lower respiratory tract infections, HIV/AIDS, diarrheal diseases, tuberculosis, and malaria.*

The WHO (2009) identified the leading global mortality risks, affecting all country income groups, as high blood pressure (responsible for 13% of deaths), tobacco use (9%), high blood glucose (6%), physical inactivity (6%), and being overweight/obese (5%). Eight risk factors accounted for 61% of cardiovascular deaths (and more than 75% of ischemic heart disease deaths) are alcohol use, tobaccos use, high blood pressure, high BMI, high cholesterol, high blood glucose, low fruit and vegetable intake, and physical inactivity (WHO, 2009). Comorbidity and generic conditions that have multiple etiologies and cross-linkages include depression, which is estimated to affect more than 350 million people globally and to be the leading cause of disability worldwide (WHO, 2011). With chemical imbalance within the brain (low levels of the neurotransmitters, serotonin, and glutamate) identified as a prime suspect, with a global incidence of around one million and rising (mortality rate = 16/100,000, or 1 death every 40 s), one outcome is suicide (WHO, 2009).

Within the context of humans' sensory capacity the disaggregated WHO data raise two critical and linked questions:

1. How many, and what proportion of the main current threats to human life can be directly sensed by the human sensory system?
2. How many, and what proportion of these threats require some created mechanism (e.g., scientific evidence, health-related information, measuring device) to be identified?

Even when a highly damaging activity, such as smoking, is voluntarily engaged in and is associated with a substantial morbidity and mortality rate, and also results in a loss of olfactory sensitivity (Smith & Seiden, 1991), warnings may be disregarded by smokers, perhaps because of the long-term and barely detectable decline in olfactory sensitivity and the rewards of smoking that operate to counter the warnings.

2.11 Summary points

An integrated multisensory system incorporating redundancy is adaptive for organisms. It gives predators more than one option for sensing prey, while for prey it enables predator detection by more than one modality (Lewkowicz & Kraebel, 2004). The receptors comprising humans' complex interdependent sensory system constantly provide multiple sensory inputs from internal and external stimuli. This sensory system is represented neurologically in all areas of the CNS and PNS, with integrative centers in cortical and subcortical structures. Sensory information may be generated or acquired with or without conscious awareness. To adapt to environmental demands, MI is a developmental process throughout childhood. One implication is that until at least 10 years of age, as children are unable to optimally use the range of redundant sensory information used by adults, they are

* Demonstrating the ability of one mosquito species' olfactory sense, when infected with the human malaria parasite *Anopheles gambiae* is more attracted to human odor than when uninfected (Smallegange et al., 2013).

vulnerable to hazards that ideally require synthesizing and interpretation of neural representation from multiple sensory channels.

Like those of all living creatures, humans' sensory system evolved over many millennia in response to a unique set of environmental stimuli, particularly those concerned with survival needs, notably avoiding threats and finding food. While our multifaceted sensory system is finely tuned to detect a wide range of threats that could harm us, it is impossible to know how much harm has been averted due to our expert sensory apparatus operating as the basis for effective avoidance responses. How many potentially dangerous situations have been curtailed, not just for individuals, but for larger groupings such as organizations and communities because someone sensed danger and took action to forestall or minimize subsequent harm is unknowable. Very occasionally such instances are recorded as "near misses," but more typically they remain unrecorded except in the memory of the individual or group experiencing them. Organizations that harness these "near miss" experiences may be more able to avert large scale disasters. However, rarely is this potential contribution originating in humans' sensory ability deliberately harnessed to assist in managing large scale risks.

Compared with extant circumstances during the vast part of our evolution, our modern-day world has created disparities such that our sensory system alone is in many cases inadequate for protecting us from contemporary threats. In the next chapter we consider multiple ways in which humans' sensory system has been enhanced and, where necessary expanded and substituted to enable us to better face the hazards of our contemporary world. We then turn to address a critical interim stage in the risk management process, the cognitive processes underlying humans' risk perception.

chapter three

Sensor technology

3.1 Introduction

A basic postulate for the development of any sensory system is that for stimuli representing either potential threat or food, there is a high likelihood that evolutionary pressure will produce at least one mechanism for sensing it. The greater the survival benefit of detecting an important stimulus, the higher will be the associated likelihood of the organism developing several sensory means to detect it. As described in Chapter 2, over countless millennia, humans' sensory system (HSS) has been finely tuned to create awareness of multiple dangers that ancestral humans and their predecessors faced. However, because technology has advanced more rapidly than it is possible for our sensory system to adapt to the plethora of dangers that potentially engage people in modern societies, the HSS is not necessarily well adapted to sense many everyday dangers now confronting us. Humans' contemporary technology-based environment, including many of its created dangers (e.g., traffic hazards, stress from work demands, iatrogenic disease transmission) has rendered our personal sensory system partially obsolete in detecting many contemporary sources of danger.

To address this issue, at least since Galileo developed the Galilean telescope in 1609, technological progress has concurrently developed numerous means of extending, enabling, and substituting our individual sensory system to detect many technology-derived hazards. As observed by Brown (2008, p. 55), "we test hypotheses about items we cannot detect with our unaided senses by introducing a device, or chain of devices, that yields an output we can detect." We continue to develop ever more sophisticated sensory devices to detect many of the newly created dangers that we face in today's world. This chapter considers some of the ways in which technology has enhanced or replaced humans' sensory system so that we are better adapted to sense dangers in our contemporary world. The tables and summary texts in this chapter describe illustrative devices or techniques grouped according to the sensory subsystem that they were developed to augment or replace, together with brief descriptions of typical or potential applications.

In parallel with technological advances in sensor technology, there is evidence that in addition to normal genetic inheritance, epigenetic changes (chemically "switching" genes within DNA sequences on/off) comprising reference to important information, for example, associating extreme events (e.g., significant threats or stressful episodes), with sensory experiences (e.g., sounds, sights, odors) can be transmitted intergenerationally (Dias & Ressler, 2013). This feature of natural selection indicates the potential for memories or developed traits to be inherited and for specific instances of dangerous or potentially harmful events encountered to be transmitted to subsequent generations. While this research is in its early stages, it suggests a potentially powerful way in which some cues to danger or stress may be an enduring ancestral legacy.

Figure 3.1 locates the HSS within a multilevel framework, which is underpinned by the physiological and neural operational layers. A wide range of devices have been designed

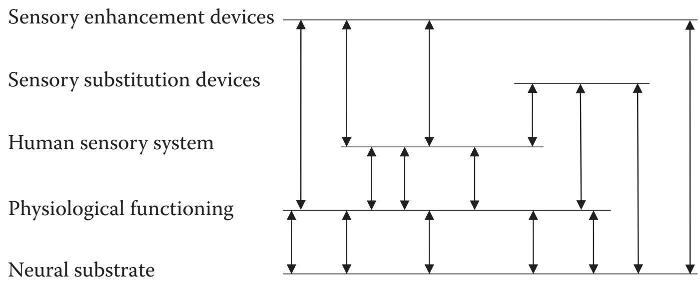


Figure 3.1 Schematic representation showing the relation of the human sensory system (HSS) to sensory substitution, sensory enhancement, physiological function, and neural substrate.

and manufactured that variously augment the HSS. Sensory enhancement devices (SEDs) may extend a human sensory component directly (e.g., telescope), or be driven by physiological functioning (e.g., heartbeat feedback), or have been developed to explore the neural substrate (e.g., brain scanning/imaging techniques). Reasons for developing SEDs in the detection and diagnosis of potential threats include the following:

1. To detect threats that the HSS cannot sense (e.g., ionizing radiation)
2. To extend the natural capacity of the HSS to identify or confirm a threat (e.g., a telescope may be used to identify approaching danger)
3. To overcome natural limitations of the HSS (e.g., x-rays to diagnose pathology)

Applications areas for SEDs include industrial workplaces (e.g., occupational hygiene), medical (e.g., diagnostic equipment), transport (e.g., aviation, marine), and military (e.g., combat equipment). SEDs may contribute in one or more of threat identification/diagnosis, measurement/assessment, analysis/synthesis, and presentation of data/results.

Sensory substitution devices (SSDs) may be driven by an alternative sensory modality (e.g., visual representation using a tongue-based sensory device), or be founded on some aspect of the physiological mechanism for that sensory modality (e.g., cochlear implant), or be developed from the neural substrate (e.g., brain scanning techniques that allow some comatose patients to respond to simple questions). Our sensory future is likely to witness the employment of an ever-extending range of SSDs (to replace lost or degraded sensory system components) and SEDs, that can be used in threat detection, as well as in a wide range of other domains (e.g., scientific, economic, leisure).

In developing advanced sensor technology, insights have often been gleaned from carefully observing and recording animal behavior. For example, to improve the stability of small drones in high wind, researchers used high-speed cameras to study how moths managed such conditions. The essential component was rapid recovery when deviation from a target was detected. The seemingly effortless dynamic soaring ability of an albatross to use low-level wind gusts to navigate the southern oceans at speed for extended periods without collision can provide clues as to how to harness such energy sources (e.g., for glider drones; Richardson, 2015). Squid and jumping spiders are among creatures known to employ a form of rangefinder vision that incorporates a blurred segment generated by the predator's movement until it is within striking distance of its prey, at which point a clearly detectable image allows accurate range detection. Sensors replicating the tetrachromatic vision of some species (e.g., kingfisher) can detect objects (e.g., sunken marine vessels) below the water surface, greatly assisting air-sea rescue operations. The sensory principle adopted by a cuttlefish to conceal itself by mimicking its current environment can be deployed to create a screen so that to an observer it appears that the screen and the concealed person/object are part of the background. While the development of radar and sonar (invented by Hiram Maxim) was driven by the notion of an active sensory system, the ultrasonic microphone was based upon bats' ability to detect fine motions of air molecules (Horowitz, 2012).

3.2 Sensor technology

Billions of sensors* are being attached to natural resources, production lines, electricity grids, logistics networks, recycling flows, and implanted in homes, offices, stores, vehicles, and human beings, feeding vast volumes of data into a global neural network—sometimes referred to as the Internet of Things (IoT). "Prosumers" (consumers who also produce/share goods/services) can connect to the network and use IoT data, analytics, and algorithms to accelerate efficiency, dramatically increase productivity, and lower the marginal cost of producing and sharing a wide range of products and services to near zero, as they have done with information goods (Rifkin, 2014). The IoT comprises the network of objects surrounding us from which data may be captured and which can be analyzed to generate pictures of individual lives (Darzentas, 2014). Data from sensor-based components of this network (e.g., smartphones, smart watches, laptops, wireless, and other smart house technology, satnavs and other in-vehicle systems) can be combined with environmental surveillance (e.g., CCTV) and agency data (e.g., credit card usage, utility consumption patterns, work and leisure journeys) to create detailed composites of people's lives. Future applications will include sensors embedded in smart materials, environments, and "intelligent products" in a wide range of sectors (Micocci & Ajovalasit, 2014).

Technological advances in sensor technology have created ever smaller and cheaper wireless sensor devices, which can be either ground-based, or located in manned or unmanned aerial, or in rail vehicles, or in maritime vessels, or installed in satellites, or designed for human portability. Integrated systems are analogous with humans' natural multisensory capabilities. Portable/wearable sensors include those measuring blood oxygen saturation level and heart rate (oximeters), metabolites, skin temperature, neural activity, and respiration, as well as accelerometers, force sensors, pressure sensors, and gyroscopes (Jia et al., 2013; Michahelles, Matter, Schmidt, & Schiele, 2003; Pan et al., 2014; Römer & Mattern, 2004). Other sensor types include seismic, inductive, and capacitive coupling, conductivity, magnetic, electromagnetic, electrochemical, electro-optical (e.g., CCTV), optical, digital-video, pressure, temperature, humidity, wind speed and direction, water current and turbidity, moisture, salinity, pH probes, oxygen sensor, audio/acoustic, oscillators, ultrasound (O'Brien, 2007), infrasound (Leventhall, 2007), nuclear, radio, micro/radar, lidar, sonar, laser, diffuse light, infrared, spectrometers, and particle counting.

Networked sensors (also known as *correlated sensor networks*, wide-area tracking systems, or sensor fabrics) dramatically enhance a system's threat-detection capacities (Hills, 2001). Networks may be infrastructure-based or ad hoc; deployment may be random or deliberate installation (Römer & Mattern, 2004). Other sensor network variables include hierarchical versus node-centric arrangement, data-centric (applications-oriented), mobility, heterogeneity, diffusion (destination node not specified), multimodality, topology,

* While Rifkin's (2014) estimate was of 3 billion current sensors operating worldwide, Fairchild Industries has estimated that there will be 100 trillion sensors globally by 2030.

coverage, and connectivity. Networking capabilities integrated by automated data fusion Bayesian probability-based systems include discarding false alarms, self-organizing, distinguishing signal from noise, substitution through redundancy in the event of one or more sensors becoming disabled, reconfiguration—akin to neural plasticity, and confirming genuine threats (Hills, 2001; Leighton et al., 2013; Winkler, Tuchs, Hughes, & Barclay, 2008). Sensor networks can also make use of preexisting communications (e.g., GPS, LAN, Bluetooth, PDA) technology (Römer & Mattern, 2004).

Reviewing various technologies and systems for assessing potential harm from escalating crowd densities in restricted locations, Yaseen, Al-Habaibeh, Su, and Otham (2013) developed a sensor fusion system incorporating data capture from an infrared imager, a visual camera, a light intensity sensor, and a temperature sensor. Integrating data from these four sources enabled the automated system to overcome the disadvantages of each independent data source, and to generate a real-time multisensory depiction of danger (Yaseen et al., 2013). Like the HSS, fusion approaches range from selecting an optimal response, to modeling techniques that assess reliability on the basis of how the data were generated (Chong & Kumar, 2003). To address some of the issues that humans' multisensory system solved long ago, engineering and scientific challenges for integrated wireless sensor networks include those identified by Winkler et al. (2008):

- Clear identification of several simultaneous events
- Reliably correlating information from neighboring nodes
- Accurate object and event classification
- Better integration of multimodal sensor types to enhance data reliability
- Overcoming interference from extraneous sources
- Improved miniaturization of sensors
- Improved sensor robustness (e.g., to withstand aerial deployment)
- Avoidance of data loops in large networks
- Improved anti-tamper devices (e.g., to reduce the likelihood of jamming/hacking)
- Improving efficiency through greater optimization
- Better data integration (e.g., for object identification and tracking)
- Agreement on standards for data and communication exchange

Application domains for sensor networks or autonomous devices include military intelligence, combat engagement, and perimeter protection (Chong & Kumar, 2003; Hills, 2001; Winkler et al., 2008), biological, chemical, or nuclear attack (Chong & Kumar, 2003), locating hidden electronic surveillance devices, explosive device triggers or timers (Leighton et al., 2013), border control (Michahelles et al., 2003), terrorism alert, community security, earthquake damage assessment, firestorm progress, and fire detection (Chong & Kumar, 2003; Hills, 2001; Leighton et al., 2013; Winkler et al., 2008), ATC and power grid (Chong & Kumar, 2003), environmental or species monitoring (Chong & Kumar, 2003; Römer & Mattern, 2004), agriculture, automated industrial production and delivery, mining, ocean currents, and glacier movement (Chong & Kumar, 2003; Römer & Mattern, 2004), triage for earthquake or avalanche victims search and rescue (Leighton et al., 2013; Michahelles et al., 2003), traffic surveillance (Chong & Kumar, 2003), lane departure and other in-vehicle warning systems (Spence & Ho, 2008; Tandonnet, Burle, Vidal, & Hasbroucq, 2014), robotics (Chong & Kumar, 2003; Pan et al., 2014), building and structure monitoring (Chong & Kumar, 2003), "electronic skin" measures in high-energy exercise or sports (Jia et al., 2013; Pan et al., 2014), and bio/medical/health care (Baldus, Klabunde, & Müsch, 2004; Jia et al., 2013; Pan et al., 2014).

Analogous with developmental and learning processes in humans' neural circuitry, wireless networks may be required to "learn" the relative importance and accuracy of information passed between sensors and nodes (Baldus et al., 2004). Baldus et al. identified several requirements for effective health care wireless networked systems:

- Patient safety
- Convenience for clinical staff
- Reliable automatic setup and operation
- Low power consumption and low storage usage
- Intuitive and easy-to-use
- Flexible action sequences allowed
- Avoidance of unintentional (de)activation or unauthorized setup
- Under clinician control
- Unique patient identifier
- Logging of identified individual user operation
- Flexibility of adding/removing sensors/nodes
- Unlimited number of sensors/nodes
- No interference with other sensor networks

Within aviation, threat detection systems operate at varying degrees of reality either by warning individuals or by alerting system users of threats to others, or distally. Aircraft warning devices, whether as sensory enhancements or substituted elements, alert pilots to direct personal (potential) threats (as well as to all those onboard). Within the ATC domain, while designed to extend or enhance users' sensory capabilities, screen displays are one step from reality in that any danger is representational and is exclusively to third parties—notwithstanding possible secondary threats of supervisory control or even dismissal for "judgment errors." In simulated aircraft environments, warning systems most evidently do not represent real threats. However, it is a standard practice for aircraft simulation programs to preclude the possibility of a pilot crashing the "airplane," thereby potentially depriving trainees of learning through error-making.

Head- or shoulder-mounted digital-video devices distributed to police forces in several countries (e.g., the United Kingdom and the United States) have reduced levels of physical violence against police officers and in person-to-person fights when approached by a police officer wearing such a device (Harris, 2010). While not without their shortcomings, these devices have improved offender admission rates and led to faster resolution of offenses, as well as changing police behavior through enhancing accountability (Harris, 2010). Where sufficient continuous tamper-proof footage exists, video recordings made by body-mounted video devices could exceed the reliability of humans' memory, for example, as has been known for some time from reports of eyewitness testimony inaccuracies (Loftus, 1980; Loftus, Miller, & Burns, 1978; Powers, Andriks, & Loftus, 1979). In addition to data collected by multiple street and building mounted video cameras, the ease with which citizen-videoed material can be collected using portable devices (smartphones, etc.) may well change individuals' behavior if it assumed that there is a high and increasing likelihood that some device or someone is recording a person's behavior (and posting the resulting footage on YouTube!).

It is certain that as sensor-based technology becomes ever more ubiquitous, human behavior will change and adapt. For example, knowledge of being observed will generate behavior change, at least for as long as awareness of the observation persists. Although there will be many health, safety, and environmental benefits of new sensor-based technologies, some long-term health and safety impacts may be unpredictable. For example, research is exploring the contrasting benefits (e.g., networked vehicle systems that can advise of dangerous road conditions) and potential disbenefits (e.g., additional sources of distraction) of new and developing in-vehicle technologies.

3.2.1 Examples of sensor technology

Tables 3.1 through 3.11 illustrate threat-detection devices or systems that extend, enhance, or substitute humans' sensory capacities. While these tabulated examples cannot be exhaustive, particularly as new applications are continually being developed, they provide evidence of humans' great efforts in expanding and augmenting their sensory system to detect and diagnose a multitude of contemporary hazards. Some of the illustrative examples include devices that may also be used in nonthreatening situations, for example, in scientific research or medical diagnosis. The glossary provides expansions for abbreviations used in the tables. These include items collectively referred to as medical imaging (part of biological imaging), incorporating aspects of nuclear medicine, molecular medicine, molecular imaging, and therapeutics (see e.g., Guy & Ffytche, 2005; Suetens, 2009). Table 3.1 outlines some devices that enhance or extend auditory aspects of the HSS.

Table 3.2 describes some devices that enhance, extend, or substitute for visual aspects of the HSS. Medical imaging techniques producing graphical representational output rather than images include EEG, MEG, and electrocardiography.

Devices that serve to enhance the tactile sense are illustrated in Table 3.3.

Table 3.4 illustrates devices enhancing chemosensory HSS features (including detection, measurement, analysis, and alerting features). Engineers are developing ever more sophisticated robotic devices that can detect odor sources characteristic of potentially harmful agents, such as fire, chemicals, or bombs (Lu, 2013).

Table 3.5 describes some devices that serve to enhance HSS somatosensory features.

Some devices with electromagnetic features are illustrated in Table 3.6.

Table 3.7 describes devices enhancing some features of humans' memory.

Various devices and applications used to enhance multisensory features of the HSS are outlined in Table 3.8.

Table 3.9 outlines some devices or applications that serve to enhance other HSS features.

Outlined in Table 3.10 are further examples of devices that serve to extend, enhance, or substitute HSS features.

3.2.2 Extending the tactile sense as a sensory substitution

By creating a synthesized form of synesthesia, the sense of touch can be used to replace both lost sight and hearing. Various devices and technologies have been developed to convert stimuli normally received by one sense modality to be received in attenuated form by a different set of receptors, for example, using touch-vibration (Zelek, Bromley, Asmar, & Thompson, 2003). While Braille has been used for many decades, technology now exists to convert sights and sounds to match touch sensations, which allow the blind to learn how to "see" (Zelek et al., 2003), and the deaf to "hear." Contemporary technologies use touch to a high level of sophistication, for example, in many computer and

Table 3.1 Devices Enhancing/Extending Auditory HSS Aspects (Including Vibration)

Device	Health/safety threat identification implications/applications
Microphones*	Sound waves move a diaphragm to create an electrical signal
PZM boundary microphones (generally used in an array)	Can detect sounds to about 22 kHz, slightly beyond human hearing range
Electret condenser microphones	Small, vibration-sensitive
MEMS microphones	Miniaturized, highly sensitivity, stable performance
Acoustic vector sensors (matchstick size, no moving parts—e.g., Microflown)	Measures air movement disturbed by sound waves to rapidly detect/transmit a sound's location—air molecules flowing across two parallel 200-nm Pt strips heated to 200°C generate temperature differences; software counts air molecules passing through gap to gauge sound intensity and coordinates of sound source from temperature changes in Pt strips; a sensor can track/identify distant airplane, mortar rounds, rifle fire, etc.; can hear/record/stream ordinary conversation at up to 20 m (future developments will extend range); signal processing software filters out unwanted noise (wind, traffic, etc.); can direct surveillance cameras to precise location of sound and record visual along with auditory aspects (e.g., target conversation) or program drone strikes; potential use in ATC systems to identify airplane movements, including direction, weight capacity, etc. (cheaper than radar and less bounded by topography)
Acoustic microsensors (e.g., used by DARPA); acoustic basis Knowles subminiature microphones (Horowitz, 2012)	Can identify features in an area based on their sound and vibration signature; information loaded to a remote server can localize distant sounds to within ~m accuracy; semi-independent modules can be dropped in large numbers from low-flying aircraft to form ground-based acoustic network arrays as part of battlefield intelligence
Geophones (seismic microphones) (Horowitz, 2012)	Detect low-frequency sound and vibration, including within the infrasonic range—earthquake detection
Seismometers	Detects surface vibrations
Miniaturized sonar devices	Fitted to vehicles as part of a collision avoidance system (people, objects); aid to visually impaired
Combined ultrasonic sonar emitters/detectors; underwater hydrophones; ultrasonic transducers (basis of sonar)	Specialized audio transducers; can detect/emit signals >20 kHz; noninvasive medical imaging; engineering applications (e.g., detecting flow rates/leaks in fluid-filled piping)
Ultrasound generators—use sound waves at millions of Hz	Create echoes for medical imaging to detect pathology

(*Continued*)

Table 3.1 (Continued) Devices Enhancing/Extending Auditory HSS Aspects (Including Vibration)

Device	Health/safety threat identification implications/applications
Ultrasonography	To study moving structures in real time, ultrasonic (MHz range) sound pressure waves and echoes inside body tissue are differentially attenuated to reveal internal structures represented as 3D images
Echocardiography	Uses 2D, 3D, and Doppler ultrasound to create images of heart and blood flow (echocardiogram)
Biomimetic cochlea-like chips	Detects radio frequencies in a similar way to the mammalian ear
Implantable miniaturized cell phones (e.g., in jaw)—radio frequency chips that send signals to inner ear	Use bone conduction for communicating—can detect speech
Radio telescopes	Convert radio signals into sound to detect emissions at vast distances
Accelerometers (vibration)	Measures acceleration (m/s^2); can identify potentially harmful levels of vibration exposure (e.g., resulting in disorders of circulation, bones, joints, nervous system, and muscles); two-axis accelerometers can be used in rescue operations to detect motion and 3D body orientation of buried casualties; used for rapid airbag deployment during vehicle crashes
Vibration mass balance—e.g., tapered element oscillating microbalance (Mark, 2005)	Continuously measures concentrations of potentially toxic airborne particulate deposition by changes in resonant frequency of a tube (vibration)
Sound level meters—e.g., personal noise dosimeter (Gardiner, 2005)	Logarithmic measure based upon the auditory sense's relative response at different (A–E) frequencies (sound pressure weights)—dB(A) weighting most commonly used, dB(D) used only for aircraft noise and to identify acute and chronic harmful noise levels
Acoustic monitors (e.g., vehicle sound system microphone)	Can be programmed to detect particular sound frequencies (e.g., breaking glass, which could signal a break in)
"Glasses" that can represent visual images as sound	Could be used to enhance VR or visual sensory experiences
Perimeter radar (e.g., as part of a vehicle alarm system)	Detects approaching objects (people, etc.); central processing unit determines, according to set criteria, whether these constitute a threat, triggering an alarm

* A history of the development of the microphone and other MEMS-based devices (e.g., accelerometer, gyroscope) can be found in Elko and Harney (2009).

Table 3.2 Devices Enhancing/Extending/Substituting Visual HSS Aspects

Device	**Health/safety threat identification implications/applications**
Spectacles/contact lenses	Bring objects into focus to help identify threat potential
Retinal implants	Compensate for retinal photoreceptor degeneration by converting light into signals to stimulate retinal ganglion or bipolar cells, which pass signals to the optic nerve
"Eyeborg"	SSD that converts color into sounds to vibrate the user's skull
Telescopes/binoculars	Can identify distal threats (e.g., predators, enemies)
Optical microscopes/scanning electron microscopes	Can detect many pathogens (e.g., particles) too small to be seen by the naked eye
Optical samplers/optical particle counters (Mark, 2005)—e.g., light-scattering photometer	Using light extinction and (laser or infrared) scattering, or direct convection, can assess real-time mass concentrations and distributions of airborne particles of various sizes
Luminance/illuminance meters (Smith, 2005)	Used to identify illuminance levels that may be too low or too high; sensor response typically corrected for color/direction
Spectroradiometers (Chadwick, 2005)	Obtain irradiance as a function of the wavelength
Ultraviolet spectrophotometry	Used to analyze concentrations of certain gases/vapors
High-definition space telescope cameras	For example, launched at the end of 2013, the Gaia space telescope with a 1-billion pixel digital camera is stable and sensitive enough to see objects 400,000 times fainter than the dimmest ones visible to the naked eye; in addition to the prime scientific objective of mapping around 1 billion stars, recording stellar relative movements, and discovering new galaxies and planetary systems, Gaia will be able to alert us to asteroids within our solar system, including those representing a potential threat to Earth

(*Continued*)

Table 3.2 (Continued) Devices Enhancing/Extending/Substituting Visual HSS Aspects

Device	Health/safety threat identification implications/applications
Windshield-mounted scanning cameras	Constantly scanning the road in front of a vehicle, using algorithms the device monitors distances to moving and stationary objects as well as detecting when the vehicle strays from its lane position without indication; used as a collision warning device (e.g., for pedestrians), by setting off a dashboard alarm, giving the driver 2.5 seconds to brake (3-month trial for “mobilege” sensors on some Sydney cabs in 2014)
Infrared cameras	Can record objects/events represented at wavelengths from around 10^{-6} to 10^{-4} m (1–100 μm); potential applications include 3D reconstruction of archaeological sites from subsurface features
Tomography (plain film)*	X-ray sources and detectors move to blur out structures not in the focal plane
(Projection) radiography*	Anatomical evaluation using x-rays to view nonuniform materials; variable density and composition (e.g., bone, muscle, fat) determines extent of x-ray absorption; rays passing through captured by photographic film or digital detector, which shows a 2D representation of superimposed structures; medical (e.g., identifying fractures, lung pathology) and industrial uses
Computed tomography (CT)*	CT scan comprising high-energy ionizing radiation generates 3D representations using computer-assisted reconstruction
Flouroscopy*	Image receptor converts constant low-dose x-ray input into screen images to guide procedures requiring constant feedback (e.g., exploratory, surgical)
Infrared spectrophotometry; x-ray diffraction; energy-dispersive x-ray analysis	Can reveal features (e.g., minute particles) not visible to naked eye
Superlenses—made from metamaterials (negative refractive index) on a scale smaller than the wavelength of light being used	Can use light harvesters to concentrate light into a tiny area (<1 nm^2); potential to make a sensor for a single molecule
Altitude alerts (visual/auditory alarm)	Passive aircraft warning system alerting pilot(s) to current altitude; enhances visual sense for altitude estimation, or substitutes in poor visibility (e.g., clouds, darkness)

Table 3.3 Devices Enhancing Tactile (For Example, Thermoception, Pressure) HSS Features

Device	Health/safety threat identification implications/applications
Sensory robotic limbs	Prosthetic device releasing infrared light and detecting the rebound before sending data to the brain to interpret as touch-like sense for artificial limb (potential for detecting frequencies beyond normal human capacity—e.g., UV, x-ray)
Thermometers: Youle (2005) described various types—e.g., mercury/alcohol in glass, electrical resistance, thermistor, and thermocouple (differential expansion)	Measure (dry bulb) air temperature to enable maintenance of safe (comfort) range in controlled environments or prompting movement to safer thermal location
Pryrometers, thermopiles	Measure radiant temperature directly, which is converted into a mean value (MRT) to assess safety level
Noncontact (infrared) surface thermometers	Measure radiation temperature of surfaces (e.g., those too hot or too cold for safe touching)
Globe thermometers (suspended freely; come into thermal equilibrium with surroundings after ~20 min)	Globe heats/cools due to radiation exchange with final temperature also a function of convection heat transfer; can also be used to measure radiant temperature indirectly ("black bulb" temperature converted into MRT)
Barometers (air pressure)	Measure atmospheric pressure (e.g., future storm warning)
Hygrometers—including wet and dry bulb (e.g., whirling), dew point, moving fabric, electronic, electrical resistance (capacitance), and chemical	Measure humidity (e.g., as alert to possible adverse weather events)
Moisture detection devices	Used to identify/locate infestation (e.g., behind walls)
Indoor climate analyzers (Youle, 2005)	Assess individual parameters affecting discomfort (e.g., radiation asymmetry, draughts)
Ultrasound speakers behind touchscreens generate beams of high-frequency sound waves linked to software to create different sensations as a user moves their hands (UltraHaptics)	Could be used as control interface in a variety of industrial and other environments (e.g., sensations include "heavy raindrops" at 4 Hz vibration, "touching foam" at 125 Hz, "strong buzz" at 250 Hz)
Heat-sensitive cameras—e.g., used as part of a system in (1) dangerous situations, (2) crowded locations, (3) at airports or other passenger transition locations, and (4) easing travel congestion in urban networks (thermoception) (Yaseen et al., 2013)	(1) Detect individuals trapped in buildings destroyed by earthquakes where it is too dangerous/difficult to send in human beings; (2) body heat readings to monitor crowd density and register potentially dangerous congestion; (3) detect individuals with raised body temperature, which could indicate infectious disease, to extend the HSS "natural" disease threat detection system, based primarily on visual (e.g., unsteady gait, skin color, prominent rashes, spots, or lesions) and/or auditory (e.g., coughing, sniffling) assessment of another's condition; (4) monitoring queuing behavior in congested city environments

(*Continued*)

Table 3.3 (Continued) Devices Enhancing Tactile (For Example, Thermoception, Pressure) HSS Features

Device	Health/safety threat identification implications/applications
"Second skin" 1 μm sensor circuits comprising aluminum oxide deposited onto a polymer foil with sensors attached to oxide layer (Pan et al., 2014)	Potential for unobtrusive medical implants or prosthetic limbs or robotic extensions (requires power supply and connective cables)
Pressure sensors (e.g., car stereo speakers operating in reverse mode)	Detect change in air pressure as vibrations, which can be used to trigger an alarm (e.g., as a system component inside a vehicle if a door is opened or a window is broken)
Shock sensors	Detect shock waves (sharp increase in air pressure followed by a sudden drop); can be used as part of a car alarm system as for pressure sensor; shock waves from nearby explosions can kill or seriously injure even if no physical injury is evident as the shock waves can cause concussions, TBI, and mental health problems
Elastography	Maps elastic properties of soft tissue; 3D image from 2D pressure maps of tissue examination
Tactile imaging	Mimics manual palpation by translating touch into digital image by applying pressure to soft tissue and generating 3D image of resulting deformation
Thermography	Uses digital infrared imaging; based on principle that metabolic and vascular activity in precancerous and area around a developing cancer are generally higher that in normal tissue; widely used for breast examination; 3 types—tele-, contact thermography, and dynamic angiothermography (more information improves diagnosis)

other product interactive interfaces (Böhmer, 2012; Nakanishi & Yamamoto, 2011; Pohl & Loke, 2012; Yoshimoto, Kuroda, Imura, & Oshiro, 2012), including VR, occupational, and gaming environments (Cameron et al., 2011). In describing touch interface technology, Böhmer (2012) distinguished between resistive touch sensing, capacitive touch (electrical), and infrared (IR). The latter operates by disruptions to patterns of IR beams reflected inside a screen. In creating technologies capable of discriminating between touch and pressure sensations, Yoshimoto et al. (2012) identified optical, acoustic, and electrical touch sensing.

Mateevitsi, Haggadone, Leigh, Kunzer, and Kenyon (2013) described the development of a "SpiderSense" device comprising highly sensitive ultrasonic microphones, akin to radar, attached at multiple sites over the body with transducers to transform information about the environment into tactile sensations. The tactile display uses the skin's pressure receptors to communicate awareness of the immediate environment by conveying information via sensor modules about the wearer's distance from objects closer than 10 m. Applications include compensating for a dysfunctional or missing sense (e.g., vision, audition), or supplementing existing senses. The latter might include helping to

Table 3.4 Devices Enhancing Chemosensory HSS Features

Device	Health/safety threat identification implications/applications
Oxygen sensors	Detect ambient oxygen concentration; can be used to report respiratory activity during operations involving live casualty burial in which rescue remains possible (e.g., building collapse, earthquake, mudslide, avalanche)
Gas chromatograph	Can detect concentrations of a wide range of toxic chemicals by microanalysis
Grab samplers—various types (Brown, 2005)	Used to collect gas/vapor samples by opening a near-vacuum container
Continuous active gas/vapor samplers—various types (Brown, 2005)	Used to collect potentially toxic gas/vapor samples by sorption or sampling bags (gaseous material); cold traps (solids or liquids); activated charcoal or silica gel (organic gases/vapors); thermal desorption agents (highly toxic/flammable materials); coated sorbents (highly reactive compounds)
High-performance liquid chromatography	Used to analyze concentrations of certain potentially toxic gases/vapors
Diffusive ("passive") samplers—various types (Brown, 2005)	Use a physical process to extract atmospheric polluting gas/vapor samples at a controlled rate
Annular/aerosol denuders	Collect gas/vapor along with air samples drawn through an annular inlet; a filter traps aerosol particles
Various air metering devices—static/personal (bio)aerosol samplers/monitors (Mark, 2005)	Can measure a range of airborne particles/pathogens and detect when a given exposure threshold (e.g., OEL, STEL) for a substance has been reached, which can be set to trigger an alarm
Bioaerosol samplers monitors—various types (Mark, 2005)	Collect/store live particulate pathogenic microorganisms
Epiflorescence microscopy; enzyme-linked immunosorbent assays	Used to detect/count viable/nonviable potentially pathogenic bioaerosol particles
Patches (e.g., 10 cm square cotton) (Cherrie, 2005)	Attached to skin surface or clothing to sample exposure to harmful substances; standard method for pesticides, also used to detect dusts, volatile organic liquids, and polycyclic aromatic hydrocarbons
Suit sampling (Cherrie, 2005)	Gives whole body sample of exposure to harmful airborne contaminants gathered from lightweight cotton or cotton/polyester overalls (including gloves and hood)
Washing/wiping	Defined areas of skin (e.g., hands, wrists) washed with a solvent or wiped with a moist cloth; contaminants collected and measured

(*Continued*)

Table 3.4 (Continued) Devices Enhancing Chemosensory HSS Features

Device	Health/safety threat identification implications/applications
Florescence (Cherrie, 2005)	Florescent compound added to contaminant source and intensity of florescence on worker's body is scanned under UV light to provide measure of mass of contaminant; provides whole body assessment of area exposed
Litmus paper	Measures fluid pH (acidity/alkalinity) to test for safety of a variety of processes or actions
Chemical sensory systems—various types—for example, using diffusion through an ion-selective electrode's membrane, which changes a resistor's voltage to reveal distinct patterns in target ion concentrations	For example, can be used to detect traces of chemicals in liquid or gaseous form that could have been used in manufacturing bombs or drugs, and that have leaked into city sewer systems or into the air above (EU-funded Emphasis Project); the underground system can be combined with an infrared laser above ground sweeping an area to search for the spectra of target gas molecules, sounding an alarm if detected and pinpointing the source location; community drug use can be detected to inform public health programs
Chemical sensor scanners	Can detect explosive/flammable substances either singly or when mixed with other substances (e.g., employed at airports or other transit areas)
Smoke alarms (visual/auditory)	More sensitive than HSS at detecting smoke particles and, providing they are adequately maintained and constantly fed by a power source, are invariant in responding to the designated hazard; tendency to "false positives"
Household gas (CO) detectors (chemosensory)	In electrochemical CO alarms the CO is converted into CO_2 by oxidation, which is dissolved in water, creating a weak acid that activates a battery in the alarm, causing current to flow and the alarm to sound
Fire warnings (visual/auditory alarms)	Passive aircraft warning systems that alert the pilot(s) to onboard fire that might not be detected if in engine or elsewhere

localize the direction of an object already sensed, easing sensory overload by displaying information (e.g., about imminent danger) through another sense (e.g., firefighters entering a hazardous environment with very poor visibility, or cyclists becoming aware of rapidly approaching vehicles), and recognizing a threat that is not detected by other senses (e.g., an attacker approaching from behind). An acuity map of the human skin

Table 3.5 Devices Enhancing HSS Somatosensory Features

Device	Health/safety threat identification implications/applications
Stethoscopes	Can detect irregularities in respiratory and cardiovascular systems to aid in diagnosing a range of diseases and poor health conditions
Heart rate monitors—various types	Report heartbeat rate; can monitor changes in heartbeat over time to determine whether resting and exercise levels are within or outside healthy range
Calorimeters	Measure/monitor bodily energy expenditure
Blood pressure monitors—various types	Reports diastolic/systolic blood pressure to ascertain whether readings are within or outside healthy range
Smartphone apps	System mimicking a neural network combines data from a phone's accelerometer and barometer sensors to estimate and present bodily energy expenditure, taking account of demographic and other relevant variables, to assist in health-directed behaviors
Heart rate sensor bracelets (e.g., Nymi, by biosecurity firm Bionym)	Read minor heart rate fluctuations; generates an exclusive individual identifier

is used to compute the minimum distance needed between two sensors in order to be sensed as two separate points. Initial trials revealed that while the device worked well in outdoor environments where the number of obstacles was low, indoor environments were more challenging as the sensor modules tended to overwhelm the user with tactile feedback (Mateevitsi et al., 2013). Illustrative devices substituting HSS features are outlined in Table 3.11.

3.2.3 Further enhancements of sensor technology

Illustrative sensor-based applications are described in Summary Texts 3.1 through 3.6. Some use interoceptive data (e.g., heart rate, blood pressure, skin conductance), while others use exteroceptive data (e.g., features of the visual, auditory, or tactile environments). A few use combinations of interoceptive and exteroceptive data. While many of these examples were in early developmental or design stages in 2014, they are intended to illustrate the potential for future sensor-based applications. In a few cases, where products and/or manufacturers are known, names have been included. However, the state at which technology advances means that by the time this book is published (or read) many will be considered commonplace, while others may have been abandoned as not commercially viable. Many of these applications have been developed using crowdfunding. As information for these applications could not always be found in refereed scientific publications, material was obtained from various sources, mainly popular science media (*New Scientist, Scientific American, Scientific American Mind, The Ergonomist, The Psychologist*) and various websites. While the text-box descriptions that follow do not explore ethical, legal, privacy, political, data ownership and control, human factors, or commercial aspects of the new technology, this is not to discount the considerable and growing importance of these elements.

Table 3.6 Devices with Electromagnetic Features

Device	Health/safety threat identification implications/applications
Compasses (various types)	Enhance sense of direction, which may have critical survival value
Flux-gate magnetometers and Hall effect devices—some have responses of several hundred Hz+ (Chadwick, 2005), electric field meters	Measure static electric fields (e.g., the Earth, thunderclouds, high-voltage dc power systems)
Personal power-frequency magnetic field dosimeters (Chadwick, 2005)	Used to assess worker exposure in certain industrial environments (e.g., steel works, foundries)
Radiofrequency measuring devices—for details see Chadwick (2005)	Either an (electric) field is sensed or power is absorbed; resulting temperature rise determined by a thermocouple or thermistor, with the measure displayed as a power density
Magnetic resonance imaging (MRI)	Use three magnetic fields to polarize and excite hydrogen nuclei in water molecules in human tissue to produce a spatially encoded signal that generates 2D images
Body density monitors (e.g., Touché by Disney Research)	Deliver tiny electrical signal when someone contacts a touchscreen; returns a unique measurement related to an individual's body density
Electrical sensors (e.g., part of car alarm system)	Detects anomalous voltage drops (e.g., if a light comes on because a door has been opened)
Electromagnetic sensors (e.g., part of car alarm system)	Monitor sudden variations in air pressure (e.g., from a shattered window or a forced door)
"feelSpace belt"	Uses 13 vibrating pads and a sensor to detect the Earth's magnetic field; information fed via a transducer to the cross-modal sensory cortical regions to enhance sense of direction
Sonification of electromagnetic and space-borne acoustic events	Enables listening to "sounds" of the sun/other stars as convection currents cycle heat from their surfaces and can detect residual microwave energy from the creation of the universe; can listen to the sound of the solar wind and its effects on Earth's upper atmosphere, which at high levels may presage threats to terrestrial or orbiting telecommunications systems
Smartphone app EnLighten (Matt Ginsberg, Green Driver)	Detects when the vehicle has stopped and combines this location with other traffic data to predict when a traffic light will change from red to green—sounds a chime to alert the driver

Table 3.7 Devices Enhancing Humans' Memory Features

Device	Health/safety threat identification implications/applications
Cameras	Extend visual memory (e.g., to record details of hazardous incidents)
Video cameras	Extend audio–visual memory (e.g., to record continuous details of hazardous situations)—as illustrated by numerous YouTube video sequences showing crash, incident, or "near miss" events in road and other environments
Video surveillance cameras	Can detect potentially threatening behaviors (e.g., in public locations, or worn by police, or vehicle mounted)
Tachograph	Record vehicle travel details—trip distance, speed, etc.
Vehicle-to-infrastructure sensors (e.g., transducer loop technology)	Record vehicle frequency, density, and speed information past a selected location
Number plate recognition systems	Record vehicle license plate details
Cockpit voice recorders ("black box")	Record all vocal communications among flight crew and between flight crew and external agencies (especially ATC)
Flight data recorders (extended memory + multisensory) ("black box")	Record various flight parameters, including all pilot instrument control commands + external air temperature, pressure, wind speed, and direction

3.3 *Detection to prevent or minimize harm*

The vulnerability of HSS features makes them potentially liable to damage, for example, through exposure to a range of environmental or workplace hazards. While aspects of managing workplace and other hazards are developed in Chapters 6 through 11, a few illustrative examples are presented here.

Vibration, comprising oscillatory motion, can be quantified by its displacement, its velocity, or its acceleration (Griffin, 2005). Vibration frequency is expressed in cycles per second (Hz); magnitude (e.g., sinusoidal motion) can be measured logarithmically in decibels (dB) (Griffin, 2005). Vibration direction is measured according to fore-aft, vertical, and lateral axes (Griffin, 2005). Vibration can impact safety by adversely affecting other sensory modalities (e.g., vision, audition) and cognitive processes (e.g., memory, learning, decision making), as well as impairing movement and creating discomfort (Griffin, 2005). Various standards define minimum health and safety limits for vibration exposure (Griffin, 2005 gives further details). Various occupational hygiene standards provide details of vibration measurement techniques (e.g., ISO, 2001a; ISO, 2002). British Standard BS 6472 (BSI, 2008) requires assessment of vibration and shock in buildings using the vibration dose value (ISO, 2001b). This standard describes two methods for evaluating vibration severity—based on vibration dose value and time dependency. While retaining their original reference date, international standards are reviewed every five years. For example, ISO 2001 standards were reviewed in 2011.

Further details on thermal environment measurement techniques are available in ISO (1998). Harmful effects can also be produced by exposure to sources generating frequencies beyond the visual spectrum. Nonionizing radiation frequencies include low frequencies (0—static fields, to 100 kHz), radiofrequencies (RF)—includes

Table 3.8 Devices/Applications Enhancing Multisensory HSS Features (in Parentheses)

Device	Health/safety threat identification implications/applications
Passive stall warning ("stick shaker"); some aircraft have active device ("stick pusher") (audio/visual/tactile)	Alerts pilot/s to clear and present danger of stall, typically on landing approach (e.g., aircraft in "nose-up" position), enhancing information from kinesthetic (*g*-force) sense; active device promotes automatic recovery
ACAS/TCAS, GPWS/TAWS (audio/visual)	Passive systems with audio, which may be discreet "attention getter" (e.g., chime, bell) or a (fe)male voice with instructions (e.g., "pull up"/"don't sink")
Pitot-static tube, rotating vane, and heated head anemometers (Gill, 2005) (tactile, chemosensory)	Instruments measuring air velocity inside ductwork or at ventilation systems' discharge points or inlets; enable assessment of ventilation systems' efficiency at capturing pollutants (e.g., asbestos fibers, various dusts and powders, metallic fumes, spray particles)
Integrating meters—e.g., WBGT (thermoception, tactile)	Combine selected measures into a single scale, which can be used for continuous monitoring; can be linked to alarm system
Smartphone app (echolocation, sense of direction)	Can aid echolocation to assist navigation
Smartphone app (vision, sense of direction)	Alerts drivers to available parking places by identifying when a vehicle driver has parked and, using data from the phone's accelerometer, when they drive away again; phone's compass reports the driver's movements after exiting the vehicle to predict when they might return to the vehicle; GPS position of a parking space can be broadcast so that other smartphone users are aware of whether it is occupied
Behavioral biometric sensors (e.g., BehavioSec) (tactile – touch + pressure)	Measures unique individual ways of behaving (e.g., using computer mouse or smartphone touchscreen) to high degree (99.7%) of accuracy (detecting criminal behavior vs. potential privacy threat)
Natural language analysis sensors (e.g., of behavioral biometric) (auditory, visual)	Parses how an individual uses small words (e.g., pronouns) to determine demographic features, eventually who an individual is by language use (detecting criminal behavior vs. potential privacy threat)
Photoacoustic imaging (visual, auditory)	Combines optical absorption contrast with ultrasonic spatial resolution for deep imaging; can be used in vivo inter alia for tumor angiogenesis monitoring, blood oxygenation mapping, functional brain imaging, skin melanoma detection

Table 3.9 Devices/Applications Enhancing Other HSS Features (in Parentheses)

Device	Health/safety threat identification implications/applications
Wind shear alerts (visual/auditory alarm substitutes for possible use of kinesthetic sense)	Predictive passive warning systems onboard aircraft; uses Doppler effect to alert pilot/s to local wind shear condition
Passive warning systems (visual/auditory alarm) onboard the aircraft it alerts pilot/s to loss of pressurization; warning system triggered when cabin (and cockpit) reach a particular pressure (substitutes for vestibular/ proprioceptive sense)	While a rapid loss of pressure is highly likely to be detected by pilots' vestibular/proprioceptive senses, a slow loss of pressure (or becoming airborne with pressurization system turned off) would be much less likely to be detected
Tilt sensors (e.g., float suspended in Hg-filled capsule) (vestibular)	Can be used as part of vehicle alarm system, monitoring vehicle inclination in case of attempt to lift onto trailer
Beta-attenuation samplers (Mark, 2005) (weight estimation)	Measure attenuation of beta-particles to determine mass of potentially toxic airborne particulate material
Anemometers—types (Youle, 2005) include: katathermometer (cooling or "down"), electrical resistance, thermistor (cooling), moving vane (mechanical action), tracer (e.g., smoke) (proprioception—velocity, kinesthesioception)	Measure air velocity either in internal (e.g., ventilation airflow) or external environments (e.g., wind speed), which might signal adverse or dangerous levels
Watches, clocks, wide variety of timing devices (time estimation)	Important where time-based events are critical (e.g., some hazardous processes, hand grenade detonation)

microwaves (100 kHz–300 gHz), IR, and UV (Chadwick, 2005). A comprehensive summary of types of ionizing radiation, major sources, dose limits, and protective measures is available in Clayton (2005).

3.4 Likely future directions in sensor-based technology

Future scientific discoveries are likely to be driven, at least in part, by humans' ability to enhance elements of their sensory system, either singly or in various combinations, to address ever more challenging threats to their health, for example, diseases such as diabetes, cancer, vascular system conditions, and tuberculosis, that are responsible for the deaths of millions every years. Sensor-based systems will be increasingly available to enhance our ability to improve safety in transport systems (e.g., road vehicles, ATC), in industry (e.g., hazard detection) and in leisure pursuits. Notwithstanding these developments, behavioral adaptation is likely to drive users to further stretch their capacity limits through increasing reliance on sensor-based technology that can alert them to danger.

Table 3.10 Devices Extending/Enhancing/Substituting HSS Features

Device	Health/safety threat identification implications/applications
Autopilot disconnect (visual/auditory alarm)	Passive warning alerts pilot/s that autopilot has been disconnected (could not otherwise be sensed)
Radar (visual or audio/visual display)	Can detect distal threats (e.g., aircraft) using radio waves (radar = radio waves beyond human sensory ability)
STCA—generally passive (audio/audio–visual); some systems give voice instructions	ATC system warning of aircraft within standard safe distance (e.g., 1, 2 km)
MSAW—usually passive initial visual display, then audio warning + visual flash	ATC system warning of aircraft below safe altitude
RIMCAS (see http://www.searidgetech.com/ansp/rimcas and www.honeywellrunwaysafety.com/smartrunway.php)	ATC system warning of aircraft on airport runway being too close for safety margins
Ionizing radiation film badges (Chadwick, 2005)	Incorporate a polysulphone film to indicate UV dose through coloration change, which can indicate UV exposure level
Radiation dose-rate meters	Used to measure external ionizing radiation levels
Radiation alarm monitors	Detect ionizing radiation
Film badges; thermoluminescent dosimeters (Clayton, 2005)	Passive ionizing radiation detectors, indicating cumulated doses; processed film badge filter gives visual record of an individual's doses of beta, gamma, and x-radiation, as well as thermal energy neutrons
Thermal devices (e.g., thermopiles, bolometers)	Measure longer IR wavelengths by absorbing incident broadband energy to increase the temperature of a sensing element, which is detected electrically
Photonic detectors (e.g., semiconductor photodiodes, photomultipliers)	Respond to incident radiation (IR) photons—can be very sensitive but with narrower band widths than thermal devices
Neural prostheses	Can detect neural transmissions to allow limited communication with some "locked-in" patients
Thermal imaging devices	Can reveal features not visible to naked eye
Whole-body scanners	Can detect objects (e.g., metal) that would otherwise remain hidden; use includes places where terrorist threats might exist (e.g., airport transit areas)
Oximeters	Measure heart rate and blood oxygen saturation (SpO_2)
Scintigraphy	Gamma cameras capture/form 2D images from radiation emitted by ingested radiopharmaceuticals

(*Continued*)

Table 3.10 (Continued) Devices Extending/Enhancing/Substituting HSS Features

Device	Health/safety threat identification implications/applications
SPECT (3D tomographic technique)	Gamma camera captures images from radiation emitted by ingested radiopharmaceuticals; detectors around body form 3D images
Positron emission tomography (PET); forms—linear, poly, zonography, helical (CT, CAT techniques use x-rays), orthopantomography	Uses coincidence detection to image functional processes; short-lived positron-emitting isotope incorporated with organic substance (e.g., glucose) to identify metabolic activity; images can reveal rapidly growing tissue (e.g., tumor, metastases, infection)
Chemical detection devices (e.g., mass spectrometers)	Can detect traces of chemicals used in explosives or drug manufacture (e.g., at airports)
Ionization chamber	Electrical device giving a direct reading of an ionizing radiation dose
Proportional counter	Electrical device giving an enhanced reading of an ionizing radiation dose
Medical imaging devices (Guy & Ffytche, 2005; Suetens, 2009)	A wide variety of these for scanning bodily features to detect pathology
Geiger-Müller tube (Geiger counter) (Clayton, 2005)	Electrical device that accelerates ions to give a large pulse in response to an ionizing radiation source; either provides warning of an ionizing radiation source (simple type), or can provide dose rates, integrated doses, with preset alarm indication when selected dose rates or integrated doses are detected
Scintillation detectors (Clayton, 2005)	Solid- or liquid-based electronic devices that use light amplified by a photomultiplier re-emitted from absorbed energy from ionizing radiation—either alpha, beta, gamma, and x-radiation, displayed as visual or audible signal
Sonar	Detects objects by advanced echolocation (e.g., in water)
ELF device (mimics pachyderms' ability to detect ground vibrations at distances of >1 km)	From an underground source, vibrations are relayed through solid rock via a transmitter to a receiver, which indicates the source from a visual on-screen signal; system driven by 12 V battery; could be used in rescue operations to locate trapped miners
Tetrachromatic color filters (e.g., comprising digital oil droplets)	A camera fitted with these sensors, which replicate the tetrachromatic vision of some species (e.g., kingfisher); able to detect objects (e.g., sunken marine vessels) below water surface, which can greatly assist air-sea rescue operations
Heat-sensitive panels	Replicate ambient temperature so as to render objects covered in them (e.g., a tank) "invisible" to infrared detection systems

(*Continued*)

Table 3.10 (Continued) Devices Extending/Enhancing/Substituting HSS Features

Device	Health/safety threat identification implications/applications
"Invisibility" screen, using the sensory principle adopted by a cuttlefish to conceal itself by mimicking its current environment	To conceal an object or person, a camera records the scene behind the item to be concealed, the resultant image being projected onto a screen in front of the object to be hidden so that to an observer it appears that the screen and the concealed person/object are part of the background environment
Geophones	Very low-frequency microphones used to record earthquakes
Seismographs	Can detect earthquakes (some animals—e.g., dogs, cattle, rats—can sense a range of "natural disasters" well before conscious aspects of the HSS operate); senses involved could be vibration (snakes), high-frequency audition (dogs, cattle)
Self-driving vehicles (e.g., "TerraMax")—operating principle based upon a seal's ability, using its whiskers as sensors, to follow the trail of a moving object through water, even in degraded visibility	Use 64 revolving laser beams as sensors (each rotating at 15 times/s, representing 1.3 million "touches" per second); detected objects indicated by a wire moving against a coil, sending a signal to a receiver, which gives appropriate instructions to the vehicle's operating system; could be used to guide unmanned supply trucks though terrain too dangerous to risk human life
Breath-testing devices (e.g., used by police at roadside units) (chemosensory, somatosensory)	Can detect alcohol levels or other drugs
Blood sampling (somatosensory)	Can detect presence of a wide range of drugs (e.g., in athletes or drivers)
Urine sampling (chemosensory, somatosensory)	Can detect presence of a wide range of drugs (e.g., in athletes or drivers)
Virtual reality (VR) systems	Can be used to detect threats in dangerous locations (e.g., involving fire or toxic chemicals); immersive systems can replicate 360° visual environments, haptically driven, and coordinated with syncronized auditory input
Augmented reality (AR) and mixed reality (MR) systems	Blend physical and digital environments, allowing virtual object manipulation within a real environment; might be used to introduce virtual hazards into workplaces to indicate their possible impact; can be extended to transmit images to remote locations for multiple user interfaces; more developed systems could use lightweight headsets
Fan blade design (based on an owl's feathers, which enable silent flight)	By "feathering" the ends of fan blades (e.g., in industrial fans, airplane engines) to reduce air turbulence, noise levels can be significantly lowered, thereby reducing noise pollution and likelihood of hearing damage to exposed individuals

Table 3.11 Devices Substituting HSS Features

Device	Health/safety threat identification implications/applications
Tactile display	Grid of rods impinging on an area of skin (e.g., back) or on the tongue, which are stimulated (e.g., mechanically or with mild electric pulses) to represent information in an external scene, which can then be sensed as visual input, or to aid balance or sense of direction
Tactile simulation (tactors)—e.g., TSAS, SOES	Vest loaded with vibration elements identifies movement (i.e., a gravity detector), which can substitute for confusion in humans' visual and proprioceptive systems, particularly during night-time airplane flight (spatial disorientation was a factor in 11% of U.S. Air Force crashes and almost a quarter of night-time crashes between 1999 and 2004)
Gravity wave detectors	Lasers bounce between mirrors inside twin perpendicular tunnels each 4 km long; a passing gravitational wave is expected to slightly change the length of one arm compared with the other, creating a detectable laser signal
Canes (various designs)	Tactile and proprioceptive input can substitute for sight
Echolocation devices—various types (either generated by a blind individual as tongue clicks, or created by a sensor/transmitter/receiver system)	Examples—for either blind individuals or sighted individuals operating in darkness: (1) speed of handheld buzzers can indicate how far an object is away from a person walking, enabling successful navigation of an environment; (2) data from object sensors on the front of a bicycle can be represented as vibrations in buttons on the handlebars, enabling the rider to ride successfully
Global positioning systems (GPS)	Enables environmental features to be represented visually on a screen to aid sense of direction

Predictions for future developments in danger sensing technology might include the following:

1. Sensor-based technology will become increasingly sophisticated, enabling new developments and enhancements of existing applications.
2. Other species' sensory systems will increasingly be studied to inspire the development of new sensor-based technologies.
3. SSDs will become increasingly diverse and user-friendly, incorporating a wider range of human factors considerations.
4. Sensor systems that can detect some of the major disease threats to human beings will be developed, particularly those affecting people in advanced economies. These might include further development of diabetes detection and behavior correction sensor technologies outlined in this chapter, cancerous and precancerous growth detection, vascular system malfunction detection, and early-stage dementia symptom detection.
5. Major areas for future development are highly likely to include those sectors already extensively using sensor-based networks (i.e., military, medical/health care, communications, scientific exploration). To these are likely to be added transport systems (including private use vehicles), leisure pursuits (especially those deemed to be "high risk"), and everyday activities. In the case of the latter, smartphone apps are highly likely to be a market-driven opportunity to use sensor-based technologies for a wide variety of functions.

SUMMARY TEXT 3.1 Sensor-Based Individual or Collective Alerting Systems for Diagnosing New or Known Preexisting Conditions

A microscope clipped onto a smartphone's camera mechanism can analyze a blood sample, which is sent to a central database to detect malaria.

A smartphone and electrode skullcap can use EEGs to determine whether individuals (particularly children) will develop epilepsy, which could be of great assistance in parts of the world where medical facilities are scarce and this condition is frequently undiagnosed (under development in 2014).

By measuring an epilepsy sufferer's skin's electrical activity (a proxy for neural activity in the brain), a smart watch app uses a computer model to detect whether a seizure is about to occur, and sends a message to the user's immediate personal contacts.

Using miniaturized electronics, a smart contact lens can monitor glucose levels in the eyes of people with diabetes.

A close-up video picture of a fingertip taken by a smartphone app can measure blood pressure to within 10% of the accuracy of a traditional clinical cuff. Inbuilt software measuring the number of red pixels per frame and how each pixel changes over time enables a proxy assessment of blood pressure and flow.

The European Virtual Physiological Human project seeks to generate digital body doubles (avatars) or virtual patients (e.g., HumMod) based on ~5000 variables describing an individual's current physiological, genetic, and lifestyle data, as well as projected health condition. Being confronted with their doppleganger's projected future state of health* might motivate people to improve their health-related behaviors. In the long term, interventions (health advice, surgery, drugs, etc.) can be individually targeted. For example, continuous bone-density sensors can be attached to people with osteoporosis or its antecedent condition to measure and record activity levels, posture, and gait. Combined with CT scan data that could reveal areas of wear, tear, or weakness, an algorithm could predict likely future health issues (e.g., fractures) connected with bone density. Links with smartphone apps could provide further personalized information. It has been estimated that continuous updating of an individual's health condition, including sensor-based tracking, will be possible by 2023.

Other health-enhancement applications include sensors measuring heart arrhythmias built into clothing (technology already developed).

* Somewhat like the eponymous character in Oscar Wilde's (1890) novel, *The picture of Dorian Gray*!

SUMMARY TEXT 3.2 Substituting Lost or Attenuated Personal Function by Sensor-Based Technology

Prostheses for individuals with quadraplegia or tetraplegia were at the developmental stage in 2014, although proof of concept had been established. Multiple sensors in an exoskeleton-like prosthesis take "instructions" from the wearer's available musculature to initiate and maintain desired movement. An extension of this system uses brain scanning to take readings directly from neural function.

A headset designed for use by blind people consists of two plates resting on the user's cheekbones adjacent to the vestibular system. External sounds are transmitted via the skull bones (Cai, Richards, Lenhardt, & Madsen, 2002) to the user's smartphone from nearby beacons and delivered to a headset via Bluetooth. A desired walking route can be pre-entered into the app, which uses feedback to maintain the user on course. If the user strays from the desired route then sound appears to be coming from the wrong direction. A synthesized voice delivers information about nearby relevant features (e.g., shops, bus stops).

Rehabilitation tools could be designed to respond to a hand grip amplified by a piezoelectric film that converted a finger touch to a changeable light response.

An eyepiece can become an SSD component in individuals with some paralysis, or deafness.

A robotic forearm incorporating a small motor and sensors that detect electrical signals in the upper arm muscles via electromyography converts the signals that drive the motor. Combining this prosthesis with a drumstick incorporating a microphone and accelerometer to sense the rhythm being played, an algorithm allows the user to play the drums at least as well as a two-armed drummer—with appropriate practice. The technology has the potential to allow any musician to experiment by augmenting musical forms.

As smart home technology develops it could be possible for multiple sound sources to largely replace or augment the tactile sensory modality for visually impaired people. One version of this potential application uses a highly directional ("hypersound") loudspeaker that enables audible sound to travel on an inaudible ultrasound carrier wave, which can be directed to a single individual. Other systems use networked loudspeakers to create wave-field synthesis, which consists of an algorithm-controlled 3D sound field. This can be controlled by a system user, for example, using designated body movements or hand gestures.

A gaze-tracking sensor that can discriminate between when a wheelchair-bound person is just looking around and when they wish to move can be connected via appropriate software to the wheelchair's locomotion unit, enabling the individual to move around by looking in the direction they would like to travel. The system is highly responsive—movement can be initiated within 10 ms of an intentional gaze, which feels instantaneous (as would any movement at <20 ms). While proof of concept was available in 2014, commercial availability was predicted by 2017. Other applications of gaze-activated technology include drone or airplane piloting.

Blind individuals could photograph a food tin label and send it with a question to a crowd sourcing site (e.g., Amazon Mechanical Turk).

SUMMARY TEXT 3.3 Sensor-Based Biometric Applications

To help strike the optimum balance between avoiding sun damage and allowing for vitamin D creation through dermal activity via the sun's rays, a wristband (SunFriend) can monitor the correct daily amount of sun exposure once a person has input their skin sensitivity (on an 11-point scale). An LED light illuminates as their UV exposure increases and lights flash when the daily limit has been reached.

Activity trackers (e.g., badge worn on clothing, accelerometer wristband, portable brainwave monitor, posture coach, GPS tracker) monitoring daily behavior (including social interactions) produce data that might be used by employers to reward certain patterns of behavior by their employees.

As well as monitoring body temperature, movement, and heart rate, wristband sleep-tracking sensor technology can give an overall sleep quality score. The data might be used by sports teams to monitor their players' sleep quality and to determine the effects of different sleep patterns on performance, as well as to design training and personal well-being regimes.

A sleep quality score is also an output from a colored pulsating spherical sensor that attaches to a sleeper's pillow to measure the amount of movement (tossing and turning) during sleep. The sensor device also tracks sounds and light levels around the sleeper, sending the data to a smartphone app to generate the sleep quality score and indicate ways of improving sleep quality. A sound alarm can be set to wake the sleeper at a time that minimizes grogginess on waking.

Individuals with diabetes can use a special camera to detect the nutritional value of food and to predict glucose levels; the diabetic information system could be extended to a visual display that includes data from insulin pumps, glucose monitors, pedometers, heart rate monitors, nutritional information from food journals, and so on.

Smart clothes could be made from fabric that glowed to communicate dynamic light effects about the environment or the wearer's walking performance. Conductive or optical sensors can be woven in to smart clothes to monitor a range of body signals including heart rate by ECG sensors on a T-shirt or similar garment, brain activity by EEG sensors in close-fitting headgear, while sensors woven into tight clothes such as cycling gear could measure how hard muscles are working. Sensors close to the chest that are sensitive to breathing movements could measure respiration rate, as well as detecting changes in body temperature and sweating, which might indicate elevated stress levels. Such devices could also incorporate a predictive function in detecting potential ill-health (e.g., cardio-vascular conditions). By shining light on the skin to measure how well blood is flowing through the capillaries (sluggish flow could indicate ulcers) smart socks incorporating plastic optical fibers might identify early-stage foot ulcers in diabetic patients. Eventually, smart socks might include sensors to measure gait, speed, and balance, analyzing the data using algorithms to predict and alert the wearer of an imminent fall. Oxygen-level sensors could detect health problems in vulnerable individuals (e.g., older people). Nightwear embedded with sensors to detect respiration rate could help sufferers from sleep apnea by triggering an alarm if sleep is interrupted by breathing difficulties. Viral or other infections could be detected by worn sensors that detect changes in body temperature, sweating, or coughing. Other potential health warnings might include chemical sensors that could detect overexposure to various substances, which could be particularly important for asthma sufferers. Other applications include military (monitoring soldiers' vital functions during combat), and medical (monitoring effects of drugs on people in clinical trials).

Smart watches (wristband sensors) incorporating visible-light and infrared spectral sensors can monitor the wearer's body movement and pulse by shining into blood vessels to provide health-relevant information (cf. fitness tracker). The watch can also connect (e.g., via Bluetooth) to a barometric pressure device in a smartphone to measure air pressure as altitude changes, for example, when climbing stairs. Connection to an accelerometer could perform a similar function. Skin conductance can also be measured through such a device, for example, to provide feedback on current emotional state.

Portable sensor-based devices that can assess 16 or more medical conditions (e.g., anemia, urinary tract infection, hepatitis A) and that can compete with hospital-lab assessments were under development in 2014. These could include camera observations of the insides of the ears and throat as well as blood and urine sampling. By analyzing blood samples, a miniature microspectroscopy lab could diagnose a range of conditions. While a prime function of such a device would be to provide reassurance—thereby reducing unnecessary visits to the doctor, data filtered through a smartphone could advise when medical consultation was needed. The device would have particularly important applications in isolated environments (e.g., space travel) where self-diagnosis could be an absolute requirement.

A bandage-like system (Bioscope project) can monitor a hospital patient's temperature (using a contact thermometer), heart rate (via electrical activity at the skin surface), movement (by accelerometer), and bodily noises (via contact microphone), transmitting the data wirelessly to a health-tracking computer system. The sensor housing is 3D printed onto the bandage, allowing staff to exchange sensors as required.

Film-like skin-mounted electronic patches containing very thin circuits, sensors, and other components, can be used to monitor: (1) electrical activity (EEG) in the brain (when forehead mounted), (2) wounds—by detecting early signs of inflammation as well as measuring whether hydration levels are adequate for proper recovery, (3) body movement (combined with accelerometer data)—for example, to assess how a patient with Parkinson's disease is moving in response to treatments, (4) in combination with memory and physiological sensors to deliver correct drug dosages, and (5) by surgical surrounding of the heart to monitor cardiac function, perhaps in combination with low-energy pacemakers or defibrillators.

A depth-sensing motion-capture camera (Microsoft Kinect) can be used to determine some human emotions using body movement data (e.g., head, torso, hands, and shoulders). Applications include training children with autism to recognize others' emotions from postural information, and providing feedback when attempting to express the same emotion by replicating the postural movements.

To mitigate the inmate suicide rate in U.S. prisons, a wall- or ceiling-mounted Doppler radar device can monitor heartbeat, breathing, and movement for signs of self-harm. The system can penetrate nonmetallic objects such as furniture within a cell. The system might also be used to monitor vital signs of life in other vulnerable populations, including newborn babies and elderly people living alone.

With resuscitation required in ~10% of births, skin-located sensor-based monitoring during resuscitation can remove the need for clinicians to suspend the process while stethoscope checks are made, as well as eliminating errors during manual heart beat counting. Using an optical-based sensor, the system (HeartLight) records cardiac synchronous variations in blood volume (pulse) from which heart rate can be calculated (Crowe, Lang, & Sharkey, 2014).

Gaze-tracking cameras that can determine where a wearer is looking can connect with other users and devices via the Internet, which the user can then select to communicate with (e.g., for information exchange).

Pill-embedded sensors (Proteus' Helius system) can track internal body states (e.g., temperature, activity levels), which could be shared with doctors or carers to help with the widespread problem of people forgetting or refusing to take prescribed medications. The sensor contains magnesium and copper, which react with stomach acid to create a charge that triggers a small electrical signal transmitted to a skin patch to record the sensor's number and detection time. A suite of sensors in the skin patch also collect data on skin temperature, activity levels, heart rate, and sleep patterns. Early trials indicated 95% accuracy in tracking patients' drug regimes, as well as high levels of user acceptance.

In 2014, the U.S. National Institutes of Health funded a 4-year "big data" project at the National Center of Excellence for Mobile Sensor Data-to-Knowledge (MD2K) based at the University of Memphis, with collaboration from 10 other universities, to translate vast biomedical datasets into usable health information. Focusing on congestive heart failure and smoking cessation, MD2K sensors gather data on heart rate, respiration, movement (locomotion, wrist, etc.), and skin conductance (a proxy measure of stress), which in combination with GPS and wireless cameras, can identify when a participant is stressed, or may be about to smoke or engage in other maladaptive health behaviors. The system is intended to change individuals' behavior using feedback and guidance from health professionals.

Natural language analysis parses individual use of language components (nouns, pronouns, adjectives, etc.)—see Chung and Pennebaker (2008).

"Digital intuition" or social-signal analysis software (Dialog by Cogito), based on voice-variation sensor technology, can monitor conversations for awkward pauses, and one-sided communication, as well as pitch, variation, and tenseness of tonality. Phone conversations can be represented visually on screen so that they can be monitored in real time, making immediate interventions possible. The system could be used to monitor cockpit communications, surgical team conversations, and customer service phone calls. As a smartphone app (Companion) factoring in GPS traces, text messaging, and accelerometer readings, it might identify possible warning signs of depression (e.g., physical and social withdrawal).

Personal authentication includes a bracelet that can read minor heart-rate fluctuations to generate an exclusive identifier.

A body density measure can deliver a tiny electrical signal to a touchscreen, which generates a unique identification signal.

A behavioral measure of touchscreen/mouse usage can detect individual users with extremely high accuracy (99.7%).

Thermostat-based sensors can map personal or household energy use to generate a unique behavioral pattern.

SUMMARY TEXT 3.4 "Biohacking" (Items May Be in Experimental or Test Phases)

Small fingertip-mounted magnets allow for the detection of electric fields.

RFID chips inserted just under the skin can be used as remote keys or for data storage.

Internal compasses can be set to vibrate when the wearer faces a particular direction (e.g., north).

Hearing can be tuned to Wi-Fi fields.

Sound conducted through cheekbone signals text or e-mail arrival, which can be sent from phone via Bluetooth or Wi-Fi—user's head tilt, wink, and so forth, displays message.

To mimic a helmet-loaded sensor system, 64 pressure sensitive pads located on the cheeks of volunteers were reported as being capable of capturing five tongue movements (swipe up, swipe down, swipe left, swipe right, and push-click) with 98% recognition accuracy. Potential applications include control of some motorcycle rider operations (e.g., signaling), and using phones or other devices while skiing or wearing a mask to protect against infection.

Certain diets might allegedly be able to trigger near-infrared vision.

SUMMARY TEXT 3.5 Security Enhancements

Energy usage has been used to track terrorist cells, which tend to favor high rise apartment blocks. Typical behavior patterns sought by security personnel include mainly low energy use and on-time payment of bills.

A wall-mounted Internet-connected device (resembling a smoke alarm) with an acoustic sensor monitors ambient noise levels within a residence. If any abnormalities (e.g., a window breaking) are detected the owner is informed via a smartphone app. Temperature and humidity sensors may also be included to detect smoke and other airborne particulates.

A wireless network of low-power radars can track movements across borders where fencing is impracticable because of cost or topographic limitations.

Military-use biodrones (e.g., for intelligence gathering) made from biodegradable substances (e.g., fungal material grown by lab-based bacterial action, proteins from nest-building insects, circuits in silver nanoparticle ink) decay if they crash, making counterintelligence based on finding or analyzing the remains almost impossible. Work was continuing (in 2014) to develop bacteria-based biosensors.

Sensors that can detect improvised explosive devices (Nixon et al., 2013).

More controversially, crowd control technologies have been developed, although deployment requires a level of community acceptance that might not be forthcoming. Rather than the brute force of water cannon, the developed technologies rely on frailties of the human sensory system for their effectiveness. They include (1) a 2 m-wide beam of microwaves (the "pain beam") that heats the victim's skin but supposedly does no permanent damage, (2) high-powered acoustic blasters that can project a powerful narrow beam of loud noise 100 m or more, and (3) a vehicle-mounted stun grenade launcher whose projectiles can temporarily disable or dazzle recipients.

SUMMARY TEXT 3.6 Enhancing Safety through Improved Detection and Analysis: Examples from Transportation, Environmental, Industrial, and Agriculture Sectors

AIR TRANSPORTATION

Multiple drone mapping, for example, of remote or otherwise inaccessible regions, can be integrated with ground-based sensor systems and also incorporate collision avoidance technology. Potential applications include flight data management and 3D flight planning.

Multispectral cameras embedded in an aircraft's nose that transmit video footage to a pilot's specially designed goggles can provide clear panoramic views of the terrain below and ahead in poor visibility conditions (e.g., fog, dust, cloud, rain, snow, darkness). The goggles also incorporate information on altitude, airspeed, and an artificial horizon to assist in flying. A depth-sensing camera on the pilot's head ensures that the displayed information moves with the pilot's head. The headset can also be linked with the aircraft's other onboard systems, for example, the traffic collision avoidance system, which monitors radar signals from other nearby aircraft. Under development in 2014, the system was scheduled for commercial availability in 2016.

Doppler radar, either onboard or at high-risk airports (Terminal Doppler Weather Radar), uses the discrepancy between transmission frequency and the frequency of returning radio waves to calculate wind direction. This system could be an important detector of microbursts, which develop very rapidly and can result in catastrophic loss of airplane control.

Smartphone technology (e.g., activity tracking app Moves by Protogeo) used by airplane passengers during disaster scenarios could augment data available from the "black boxes" by helping to diagnose critical features of an accident, and could be available in the phone's memory even if it is not being used. Accelerometers (sensing motion), gyroscopes (detecting orientation), and air pressure monitors (measuring altitude), could provide vital clues about airspeed, direction, orientation in space, and perhaps cabin air pressure. Magnetometers (measuring the Earth's local magnetic field), as well as temperature and humidity sensors, available in some smartphones could also provide valuable information.

In Australia, CASA has developed a dangerous goods app to help air travelers check whether an item (e.g., lithium batteries, gas cylinders, lighters, matches, ammunition, fireworks, paints, chemicals) is banned on aircraft, or should be specially packed, consigned, or placed in checked-in luggage.

ROAD TRANSPORTATION

Mechanical problems in vehicle engines or industrial equipment could be diagnosed using acoustic sensors. Alternatives include AR systems that can be used in diagnostics (e.g., Audi, Samsung). Such systems could be extended to incorporate engine tuning and other basic service functions.

By using a smartphone's sensors to detect when a vehicle has stopped and combining location information with current traffic data to predict the length of a stoppage, a smartphone app can predict when a traffic light is about to turn green. A chime alerts the driver seconds before the green light appears.

GPS technology is used by some trucking companies in Australia (e.g., Linfox, McAleese, Toll) to track drivers' movements, for example, to ensure that they take adequate breaks and don't break speed limits. The device can also monitor braking and acceleration. Smartphone devices can also perform these functions. British and U.S. companies have developed a range of apps that, as well as tracking driving, can also exclude distractions (text messages, e-mails, phone calls, etc.). The technology can be extended for parental or insurance company monitoring. For example, in 2013 an Australian insurance company (AAMI, parent company Suncorp) launched a safe driver app that can provide feedback on driver performance, rewarding drivers (with free roadside assist) who complied with road rules and demonstrated good driving habits. Unlike the NSW government's Speed Adviser app, the AAMI app does not distract drivers by telling them if they are speeding.

To reduce accident rates and improve traffic flow, in-vehicle sensor systems can connect with traffic signals that are currently out of line of sight (e.g., around a corner or over the brow of a hill) to provide information to the driver on the state of a traffic signal or congestion ahead. The system was being trialed (2014) in some Australian trucking companies.

In-vehicle radar can provide warning of approach of other vehicles or of impending collision.

In early 2015 Norfolk County Council in the United Kingdom trialed a portable system (designed by Dereham-based Westcotec) to detect mobile (cell) phone use in moving vehicles. The system uses a roadside sensor to monitor oncoming vehicles, which flashes a warning to the driver if mobile phone use has been detected. Driver phone use can be distinguished from passenger phone use, and the system can also discriminate between handheld and hands-free (still legal at that time in the United Kingdom) devices.

By 2015 self-driving vehicles were under development in several companies, including Apple, BMW, Google, Tesla, and Volvo. Volvo's autopilot intelligent steering and braking technology incorporates a network of sensors, including seven radars, 12 ultrasonic sensors, five cameras, and a laser scanner, which are linked to cloud-based positioning systems. If a driver failed to take control of the automated vehicle when required (e.g., in bad weather), then the vehicle would bring itself to a safe stop.

Driverless vehicles could navigate using ground-penetrating radar fixed on the vehicle's underside to compare its position with surveyed underground locations of pipes and cables, thereby overcoming some shortcomings of vehicle-mounted laser and optical sensors, which can be confused by snow, fog, or road surface reflections.

If installed universally, vehicle-to-vehicle radio-signal technology would enable vehicles to communicate with each other, thereby enabling sharing of data about speed, direction, and other potentially useful information that a driver can use to assess conditions ahead and potentially avoid collisions. For example, the sensor-based technology could rapidly (<1 ms) inform a driver in a line of cars that a lead vehicle was decelerating sharply with an instruction also to brake.

Embedded in a driver's seat electrocardiogram sensors that can detect heart signals indicating that a driver is beginning to lose alertness could save many lives (under development in 2014). The information could also be transmitted over a wireless system to a control center in case other action is required (e.g., deploying an emergency service vehicle to assist a driver).

With three times the shock-absorbing capacity of a traditional cycle helmet (as independently tested by insurance company Folksam), a clip-on collar-worn hood device (Hövding, Alva Sweden), analogous with the airbag component of a car's collision system, contains motion sensors that can detect momentum changes typically encountered in cycle crashes. When the device detects an impending crash, helium from a cartridge inflates the hood before the rider's head makes contact with an object or surface and maintains the inflation for a few seconds to protect against secondary impacts.

A smart bike (Vanhawks Valour) seeking to make city cycling safer uses sensor technology to vibrate the handlebars when a vehicle is present in the rider's blind spot. Navigation features include an LED flashing light connected to the rider's smartphone to indicate route information, while a gyroscope and magnetometer detect adverse road conditions such as potholes and uneven terrain, which are committed to the device's memory. As well as learning to avoid traffic and steep hills, the bike can communicate with other Vanhawks bikes to exchange useful information and identify current locations. A stolen bike can notify its last known location by communicating with another Vanhawks bike nearby.

MARINE TRANSPORTATION

While rogue waves may be detected by satellite tracking sensors for shipping warnings, many large oceangoing ships carry their own wide-sweep radar sensors to measure wave heights. Computer software translates the radar echoes into 3D maps of the immediate surroundings. Predictive software that can flag potential indicators of a sea that is about to go rogue (e.g., quickly changing winds or crossing seas), would be a valuable addition to current systems. Similar technology could provide advance warning of tsunamis, cyclones, hurricanes, and tropical storms.

A device that could help to counter piracy (WatchStander), which is a problem for shipping in some parts of the world's oceans, consists of shortwave radar sensors on each side of a ship that scan the surrounding water to identify small objects (e.g., fast-moving skiffs commonly used by pirates) appearing to move in an intercept pattern. By sounding an automatic alarm and activating a powerful confusing strobe light beam in the direction of the intruder, the device can warn approaching vessels and alert the host ship's crew to engage other countermeasures.

A deep ocean acidity (pH) networked sensor system (proposed in 2014) could detect how much carbon absorbed near the sea's surface has been stored in the ocean depths, thereby helping to monitor the carbon cycle, which underpins basic seawater chemistry and airborne oxygen generation. Threats to marine ecosystems (e.g., coral, fish stocks) as well as knock-on effects upon the extra-marine environment could also be better identified with this vital additional knowledge about global ocean acidity levels.

ENVIRONMENTAL APPLICATIONS

While movement sensors have been part of many security lighting systems for some considerable time, a Copenhagen experiment (begun in 2014) is scaling up this sensor-based technology to reduce expenditure on the city's lighting costs by automatically switching off street lights whose sensors detect no recent nearby movement. To determine the conditions under which the lights are operating, other sensors incorporated in the system include those measuring traffic density, noise, weather conditions, and UV radiation. The networked sensors enable entire system monitoring by transmitting data to a central location, where a decision can be taken, for example, to take action if an unusual event is detected. Such a system, if extrapolated to a vastly greater scale, could dramatically reduce greenhouse gas emissions. Other cities (e.g., in Spain, the U.S.) were undertaking similar experiments. For example, in Chicago, sensors located on street lights can track pedestrian and vehicular traffic, data from which could be used to advise pedestrians of the safest and most smog-free routes.

In a trial in late 2014 in Pittsburgh, Pennsylvania (Breathe Project), high-definition cameras allowed residents to monitor air pollution in their cities, both in real time and as 12-month archived footage. The Breath Cam system, developed with Carnegie-Mellon University's Robotics Institute CREATE Lab, comprises six sensors and four high-resolution cameras, which capture air pollution and display the data online, including fine particulates, temperature, sulfur dioxide levels, humidity, and wind direction.

A wireless network of low power radars can track movements within a forested area, which can help to keep villagers and their cattle safe from tigers, and big cats safe from would-be poachers. Radar reflecting off different objects creates distinct patterns, which can be compared with known signatures (e.g., for human or tiger movements). Wardens can be alerted when a tiger leaves the reserve or when a human enters it. Detection systems with the same objectives, based on infrared and underground fiber-optic technology, which detects slight pressure changes at the surface, have also been developed.

To reduce the likelihood of being burned by hot household appliances, thermochromic polymers could convert object temperatures into colored visual effects.

INDUSTRIAL APPLICATIONS

Sensor drones can be used to provide close-up images of structures such as electrical towers, making direct human inspection redundant.

Laser scanning technology can reveal features of the internal structure of buildings.

Vehicle-based, airborne, or ship-borne methane (CH_4) detectors (e.g., Gasbot can detect CH_4 at concentrations of 5 ppm) can identify and map gas leaks from underground pipes, bodies of water, or industrial sites, to save money, reduce greenhouse emissions, and mitigate explosion risk. Analogous technology can also be used to detect other toxic substances, including nitrous oxide, quartz dust, and lead. A lidar-based system can be used to detect leaks from landfills and oil refineries. Countries in which these systems have been trailed include Austria, Sweden, United Kingdom, and the United States.

Networked water-pressure sensors that can take readings every millisecond can detect changes in water pressure across a water grid servicing a city or other large community. The pressure change generated by a leak can be detected throughout the system. The sensors transmit information to a central server that triangulates the data to locate the leak's source. The range of sensors can be extended to include pH, temperature, electrical conductivity, and other measures, for example, to detect water contamination.

MEDICAL APPLICATIONS

Sensor-based technology is used extensively in medical training and enhancing surgical procedures.

AGRICULTURAL APPLICATIONS

Around 70% of the world's freshwater is used in agriculture. Electronic sensors measuring soil temperature and moisture content can be ploughed in to the ground and left for years without maintenance to gather data. Using RFID wireless technology via a tractor moving over the sensor network nodes, data are transmitted to a base station, enabling better decision making about irrigation to ensure optimum water use, thereby improving crop yields with a potential saving of up to 40% of previous water use. Systems were being trialed (in 2014) in the United Kingdom and the United States.

chapter four

Perceiving risk

> The price we pay for a better life is … not just the price of risk and danger and pain. It is the price of *knowing* risk, danger, and pain.
>
> **Damasio (1999, p. 316)**

Invoking the approach to sensation and perception pioneered by Gibson (1966, 1979), Auvray and Spence (2008) identified sensation as essentially the passive receipt of information from the world (or from one's body), while perception involved using that information to enable the organism to function appropriately within its environment. While sensation describes how the senses are affected by stimuli, perception constitutes the coding and categorization of those stimuli.

For any organism to survive and remain safe, accurate risk perception is a critical cognitive skill. To survive, all animals must assess risks to their safety in order to engage in life-saving behaviors. For example, in assessing the likelihood of being struck by a vehicle and to enact an appropriate response, birds can remember the typical speed at which vehicles travel on that section of road and adjust the distance at which they take off before a vehicle arrives, irrespective of the actual speed of that vehicle (Legagneux & Ducatez, 2013). Figure 4.1 shows the relationship between sensing, perceiving, and managing risk at agency, conceptual and process levels.

4.1 Risk perception or threat appraisal?

The expression threat appraisal appears frequently in the psychological literature, particularly that originating in the experimental tradition. This term implies that an organism is faced with a stimulus that could potentially cause it harm and that the most benign outcome would be neutral—that is, no harm occurring. Also a cognitive process, risk perception requires stimulus appraisal, which could involve harmful or neutral outcomes. However, as the concept of risk implies that positive as well as negative (or neutral) outcomes are possible, in some circumstances positive outcomes could occur. Therefore, threat appraisal (or threat perception) is a subset of risk perception, albeit an important one. In this book the term *risk perception* is preferred for its wider scope, although in many instances the terms are effectively synonymous. "Threat" is often used where outcomes are either harmful or neutral. Hagenaars, Roelofs, and Stins (2013) identified the complexity of threat detection (risk perception), as involving both immediate and sustained responses, as well as various functional systems, particularly attention and memory.

Table 2.10 revealed a fundamental feature of human mortality, namely that a very large percentage of us will die of disease rather than our lives ending in a traumatic incident, such as a road traffic crash or an occupational accident. This means that while we may to a greater or lesser extent be alert to the possibility of traumatic injury or even attack by a human or nonhuman agency, logically the focus of our risk perception should be on long-term threats to our health rather than on the possibility of meeting a traumatic death. This may present something of a conundrum for our risk perception.

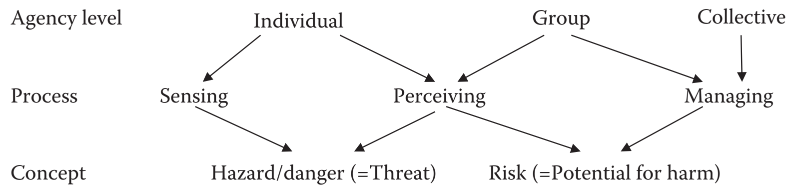


Figure 4.1 Interactions between levels of sensing, perceiving, and managing risk.

As it is likely that ancestral humans reached the apex of the food chain relatively recently in historical perspective, our evolutionary heritage has primed us to be aware of, and to fear, potential predators, particularly at night. Some of the few remaining contemporary hunter–gatherer societies may suffer high mortality rates by predators (e.g., 1 in 10 males of the Aché tribe in Paraguay are killed by jaguars, mainly at night, although the rapid disappearance of these predators through hunting and habitat loss will probably ensure that their predation is time-limited). As well as large carnivores, dogs, many snakes, spiders, and some insects can trigger the threat detection system that prepares the body physiologically and emotionally for escape or combat. One legacy of our generalized threat-detection system is that it is easier for city dwellers to acquire phobias of snakes, spiders, or dogs than of more immediate threats such as traffic, or longer-term harm from poor diet or climate change.

Thus, for most of our evolutionary development our ancestors, including long extinct far from human species, were primed to be aware of immediate threats to their safety and survival. As noted by Grinde (2013), human feelings and awareness evolved only where they made evolutionary sense. Thus, we may be unaware of a tumor unless it happens to press on nerves that evolved for other purposes. While the era during which this transition occurred remains speculative, only once humans became "top predator" a few millennia ago, enabling a significantly extended lifespan, did more long-term threats begin to assume a relatively much greater importance. Therefore, a difficulty for human risk perception, and for those seeking to educate and inform others about risks that are most likely to harm them, is how to overcome the powerful evolutionary legacy to be alert to immediate risks (e.g., traumatic injury) rather than to accurately appraise long-term threats (e.g., cancer, diabetes), that contemporary humans are much more likely to succumb to.

Threats to humans may be considered at three levels. The first level is represented by immediate threats to our safety and individual survival. This is illustrated by traumatic deaths resulting from severe injury, occasioned either at work, on the road, in domestic or leisure pursuits, or through aggressive acts including, war, homicide, and terrorism. Our risk perception mechanism is highly primed to recognize and to take action to counter threats of this type. Some illustrative attempts to extend, enhance, or expand upon humans' evolved threat detection mechanisms are described in Summary Text 4.1.

The second level of threat is represented by the majority of causes of death outlined in Table 2.10, namely life-threatening pathology, headed numerically by heart disease, stroke, and respiratory diseases. Appraising these threats requires a risk perception mechanism that can envision a time-factored dimension such that the threat may not be readily manifested within the current time frame but has its effect in the future. Appraising this type of threat requires an individual to be capable of perceiving their future selves and to envision an abstracted construction of their future health. Such a construct is only accessible via the imaginary "time travel" referred to in Chapter 2 in the discussion of our sense of

SUMMARY TEXT 4.1 Sensory, Cognitive, and Auxiliary Threat Detection Exemplars

The substantial amount of data on a vast range of environmental conditions collected by billions of sensors (e.g., creating surveillance video footage) worldwide requires massive dedicated computational power for meaningful interpretation. While numerous types of sensors have been developed to detect a new range of dangers, many of them human-generated, the extent to which risk perception can be appropriated by computers remains problematic. Here, two examples illustrate the extent to which human sensory and cognitive functions might be appropriately combined with technological interventions to enhance threat detection systems relevant to certain contemporaneous risk factors.

While face-recognition software is highly reliable within constrained situations (e.g., passport control operations), it is insufficiently portable or accessible for resource reasons to be available in all situations for which face recognition is important. Such systems are also much poorer at recognizing degraded, partially obscured, or deliberately altered facial images, which are often better detected by humans. At issue is the extent to which humans' facial recognition abilities can substitute for technological systems. A highly heritable and cortically domain-specific trait (Duchaine & Nakayama, 2006; Wilmer et al., 2010), being an evolved capacity essential to face-to-face social interactions, facial recognition is increasingly important in identifying often degraded images of wrong-doers engaging in a range of criminal behaviors (Davis, Jansari, & Lander, 2013).

Individuals differ markedly in their facial recognition ability (Wang, Li, Fang, Tian, & Liu, 2012), from complete absence in prosopagnosia (estimated as affecting ~2% of the population in its developmental form) to a recently formally acknowledged characteristic of "super-recognizers" (also estimated to be ~2% of the population), for whom faces following even a brief meeting can be recalled on a second encounter many years afterwards (Russell, Duchaine, & Nakayama, 2009). Individual differences in facial recognition are predicted by extraversion (Li et al., 2010) and have been found to be most accurate for within-racial group members (Hourihan, Benjamin, & Liu, 2012), both of which could be crucial for determining the likely accuracy of eyewitness testimony (Bindemann, Brown, Koyas, & Russ, 2012).

While some super-recognizers may consider their special ability to be a liability, possible threat detection and deterrence roles for such individuals include police work and surveillance operations in airports or other transit security locations (Davis et al., 2013). Tests to identify such individuals (e.g., Cambridge Face Memory Test—Russell, Duchaine, & Nakayama, 2009; Glasgow Face Matching Test—Burton, White, & McNeill, 2010) in a range of situations could benefit threat detection and deterrence, for example through would-be criminals learning about raised detection likelihood. The general rule that if a trait differs between individuals then it can be selected for, developed through experience, and can be trained, leads to the conclusion that developing such training could enhance many individuals' facial recognition ability. Invoking the long-established ergonomic allocation of function principle, appropriate combinations of technological and properly selected and trained individuals could enhance the effectiveness of a number of currently deployed threat detection operations that depend on accurate facial recognition.

The second example relates to the use of thermal imaging, for example, in detecting deception at airports or other transit locations where security is vital. Sensing facial temperatures above the normal range through increased blood flow as its critical feature in detecting deception, use of such technology on its own in a threat-detection role can be problematic because increased blood flow can occur for reasons other than deception (e.g., anxiety about flying, excitement at seeing a loved one, or certain medical conditions).

Investigating experimentally whether thermal imaging could have a more targeted role if used in combination with interviewing, Warmelink et al. (2011) initially found relatively poor accuracy rates for correct identification of both truth-tellers (64%–68%) and liars (62%–69%) for skin temperature methodology alone. Outperforming the thermal imaging technology, trained interviewers achieved 72% and 77% accuracy rates for truth-tellers and liars, respectively. Cues successfully used by interviewers included speech patterns and postural demeanor as well as story contradictions and answer plausibility in response to questioning. Of particular note was that while people are generally well practiced about lying over their previous behavior, they are less likely to be able to construct coherent narratives about their future intentions.

Targeting their questions about intended future actions (e.g., criminal activity) enabled the interviewers to obtain relatively better levels of accuracy, for example, by detecting fear-related responses (Warmelink et al., 2011). Crucially, during interviews, liars' facial temperature increased more than that of truth-tellers as detected by thermal imaging. The importance of structured interviewing of passengers was highlighted by Ormerod and Dando (2014), whose controlled cognitive engagement screening technique enabled security agents to identify 66% of deceptive (mock) passengers, compared with 3% using intuitive supposed signs of deception (e.g., lack of eye contact, fidgeting, nervousness). Practically, while only a tiny proportion of airport passengers can be interviewed, even a perceived raised possibility of detection could serve to reduce criminal activity through this travel mode by a deterrence effect. To increase the diagnostic capability of airport security detection systems, thermal imaging might thereby be combined with structured targeted interviewing.

---

time, or by technology that can project our future state of health (described in Chapter 3). However, attempts to communicate risks to health that may have their late-stage effects up to decades in the future are likely to be challenging to devise. Vast resources have been devoted to generating awareness of health risks from such agents as smoking, poor diet, lack of exercise, safe sexual practices, sun exposure, alcohol and other drug use, as well as various other lifestyle choices. Even more challenging are attempts to change individuals' behaviors with respect to these and other agents of long-term harm. Psychologists and other social researchers have devoted many research hours to developing and improving concepts, theories, and models that can usefully inform these attempts at increasing individuals' personal awareness and encouraging behavior change.

However, a third level of threat that is becoming increasingly relevant to human harm is even more difficult to appraise because of its problematic and not immediately obvious links to human health and safety. It differs from the first two threat levels because of its scope, its nature, and the intellectual processes required for its recognition. Probably the best example of this type of threat is climate change, which is global in scope, difficult to understand, and most critically for risk perception, involves comprehension beyond humans' normal sensory and perceptual abilities. Appraising threats at this third level requires humans to have at least either a basic understanding of science, or to trust teachers and other communicators who can inform them about the relevant science. It requires individuals to have access to and a willingness to inform themselves about the relevant science, as well as the freedom to access this information. It may also require the ability for autonomous thought, such that entrenched political and religious dogma is not appraised as an acceptable surrogate for the superordinate threat. One way of meeting the communication challenge of informing people about climate change risk is to link their personal experiences of such phenomena as drought, extended periods of temperature extremes (e.g., heat waves, cold snaps), forest fires, hurricanes (and cyclones), and flooding, to the superordinate risk.

Thus, while all three threat levels are theoretically amenable to reasonably accurate appraisal and can motivate behavior change, in practice, the first is generally much easier to perceive and to communicate about effectively. The second threat level generally requires a much more elaborate and theoretically based approach to understand and to communicate effectively about. Due to its global scope and lack of immediate evidence, threats at the third level may present the greatest challenge for risk communicators and educators as well as for risk management. Other risks that might be represented at this third level may have more local effects in the short term, but will often have much wider long-term impacts due to global population movements and the interconnectedness of human society. These include

- Water shortages (e.g., from unregulated use, damming and irrigation projects)
- Rising groundwater salinity levels
- Extensive environmental pollution
- Unsustainable fishing
- Collapsing ecosystems due to resource over-exploitation and species extinctions
- pH imbalance in oceans, lakes, and river systems
- Global financial collapse
- Nuclear war
- Almost complete depletion of readily accessible oil and other fossil fuel reserves
- Global pandemic of a virulent disease with a high fatality rate, for example, arising from a mutated virus that is airborne and transmissible via human vector

Often involving multiple jurisdictions with very different cultural, norms and values, threats arising from these features of our contemporary world are particularly difficult both to appraise, and to manage. Some of these issues are revisited in the chapter on risk management.

Although outside the scope of this book, a fourth level of threat may be identified. While threats at this level might fall within the scope of human imagination or scientific discovery (or science fiction), because of their existential nature, they are highly problematic in terms of traditional risk management, mostly falling into the high consequence low probability zone. Thus, identifying, evaluating, and managing such existential threats is often extremely difficult and ultimately may be uncontrollable. Examples include a large asteroid strike, a massive volcanic eruption plunging the world into an extended ash-driven "winter," extensive solar flares affecting all terrestrial and orbiting electromechanical systems, a nearby supernova, extinction of the human "Y" chromosome, extensive depletion of the ozone layer resulting in massive ultraviolet (UV) exposure, the next Ice Age, and alien invasion (Neal, 2014). Doubtless other existential threats may be identified.

Major challenges for researchers and risk practitioners include translating scientific knowledge, particularly when this is experimentally derived, into applications-based practice. The extent to which research based on conceptualizations of risk can contribute to practical risk management, effective risk communication, and sustainable behavior change strategies may be determined once a review of potentially relevant research has been considered. The remainder of this chapter explores some contemporary risk and cognate research fields. Most of the material described in this chapter is at the three basic levels of the model outlined in Chapter 1—risk-related behaviors, cognitive/affective features, and neural correlates. A continuing theme throughout this chapter is that, like all aspects of cognition, affect, and behavior, when applied to risk issues, these human attributes can best be understood within an evolutionary psychology (EP) framework. This is because all our risk perception and associated emotions, beliefs and behaviors have been honed over countless millennia to the extent that their response to contemporary risks may occasionally appear bizarre and inappropriate. However, an EP approach can frequently reveal an adaptive history for much of humans' observed features of risk perception and associated cognitions and emotions.

4.2 Danger perception

A series of experimental studies by Anelli and colleagues have helped to shed further light on how danger is perceived and the neural correlates of danger perception. Using the priming paradigm—in this case a grasping hand (male or female) versus a flat hand (male or female) or a robotic hand, Anelli, Nicoletti, Kalkan, Sahin, and Borghi (2012) considered the vulnerability gradient within the context of dangerous objects, motor resonance, and affordances (environmental properties relevant for an organism's goals). It was revealed that children (aged 6–8 years) clearly distinguished neutral from dangerous objects (the latter produced an interference effect) and biological from inanimate agents (with faster responses for human hand primes). The vulnerability gradient reflected the degree of inhibition from female hand (most) to robotic hand (least). Motor resonance was greater for high similarity between the hand prime and the participant's own hand (Anelli, Nicoletti, et al., 2012).

Adopting the same paradigm to study teens and adults, Anelli, Ranzini, Nicoletti, and Borghi (2013) used a line bisection task to explore graspability and embodied cognition. The researchers found that sensitivity to dangerous objects was maintained across the lifespan, and that danger perception was not confounded with action primes (e.g., grasping hand) so that motor resonance was not required to process dangerous objects (Anelli, Ranzini, et al., 2013). Dangerous stimuli were processed more efficiently than non-dangerous ones—attributed to a threat-superiority effect operating such that threat modulated visuo-spatial attention allocation. The graspability dimension was revealed as important in processing danger due to an affordance effect, so that if an object is graspable (e.g., knife) then it was perceived as more aversive, in this case being attributed to an avoidance effect. The authors surmised that the canonical neuron system, which is activated both during object-directed actions and observing those objects, may underlie the affordance effect, at least when processing dangerous objects (Anelli, Ranzini, et al., 2013).

The same priming paradigm was used by Anelli, Borghi, and Nicoletti (2012) to discover more about the role of empathy, as encoded in parietofrontal networks (left premotor cortex—PMC and inferior parietal lobule) as action potentialities. It is known that resonant activation of the pain network (cortical motor system) occurs in an observer's sensorimotor system when viewing pain inflicted on another via the mirror neuron system (MNS, premotor and parietal areas) and that pain empathy involves bilateral anterior insula (AI) and anterior cingulate cortex (ACC) activation. For both adults and children, graspable objects activated a facilitative motor response, while dangerous objects (e.g., broken glass, knife) evoked aversive affordances. While danger is perceived very early in neural processing, dangerous objects may take longer than neutral objects to process due to an interference effect, for example, due to an emotional component of these objects, which generates slower reaction times (RTs), or a selective attention mechanism, or two separate mechanisms involved in cognitive and emotional conflict. The lateral prefrontal cortex (PFC) resolves cognitive conflicts, while the rostral ACC and amygdala are involved in resolving emotional conflicts. The PFC is involved in both inhibitory and excitatory control, while the inferior post-central gyrus is activated by dangerous objects. The authors surmised that possible ancestral role differentiation (hunting vs. gathering) could account for sex differences in responses to object categories and associated hand poses (Anelli, Borghi, et al., 2012).

To explore conceptual and motor system development, in a fourth study Anelli, Nicoletti, Bolzani, and Borghi (2013) used dynamic and static presentations to explore dynamic affordances and the escape-avoidance effect for dangerous objects. Spatial and temporal effects were obtained. Dynamic condition responses were modulated by object movement direction, with dangerous objects provoking an escape-avoidance effect. Dangerous objects were processed faster when moving away from an observer (activating the escape/avoidance mechanism) and more slowly when moving toward the observer, constituting a "blocking effect." In contrast, neutral objects were processed faster when moving toward an observer, representing a dynamic affordance effect. However, the differences, while significant, were very small (~10 ms in each case).

Neutral objects were processed faster than dangerous objects (as were big rather than small objects), which was attributed to an interference effect or an aversive affordance effect. The authors suggested that dangerous objects required longer processing time because of the need to make a correct decision (e.g., escape). Large dangerous objects (e.g., close by) could initiate either a freezing (instinctive) effect or required more cautious movement (intent). Different categories of information about a stimulus (e.g., size, dangerousness) were processed separately but were rapidly integrated for potential action. The interference effect (represented as slower RT) was created by dangerous objects, while a facilitation effect (faster RT) occurred for neutral objects (Anelli, Nicoletti, et al., 2013).

Using the notion of peripersonal space (private area within arms' reach) to explore visual perception of dangerous objects, when considering their orientation, reachability, and embodiment, Coello, Bourgeois, and Iachini (2012) found that peripersonal space was reduced (on average by 1.25 cm) when the threatening part of dangerous objects was oriented toward a person (i.e., a dangerousness × orientation interaction). It was concluded that peripersonal space has both a safety value and an action value (Coello et al., 2012). Studying biases in the visual perception of spiders, Witt and Sugovic (2013) considered action-specific perception, speed perception, and affordances. It was revealed that selected perceptual biases in response to potential threats could enhance survival likelihood, particularly when associated with fear. While threatening objects (spiders) appeared to be moving faster than non-threatening objects (balls or ladybugs), the perceiver's ability to respond to the stimulus also influenced its perceived speed—the object seemingly moving faster when it was more difficult to block (Witt & Sugovic, 2013).

Speed perception was governed by multiple affordances (Witt & Sugovic, 2013). It was suggested that different neural mechanisms (premotor for ease of blocking; amygdala for threat perception) and visual pathways could be responsible for guiding the blocking action (dorsal, unbiased perception) and speed perception (ventral, implied bias). Four independent action-related factors influenced perception: (1) likelihood of successfully completing the action, (2) cost to perform the action, (3) benefits to successful performance, and (4) penalties associated with failure (Witt & Sugovic, 2013). These factors bear remarkable similarities to variables in a number of social-cognitive models that describe cognitive effects on various health outcome behaviors. A functional magnetic resonance imaging (fMRI) study of peripersonal space was the basis for Lloyd, Morrison, and Roberts (2006) study of the network for visuospatial encoding of aversive stimuli and neural correlates of danger perception. It was found that by integrating visuospatial and somatosensory information to shape an appropriate motor response, the contralateral posterior parietal cortex (PPC) could discriminate between painful and nonpainful stimuli. It was concluded that posterior parietal areas that respond to visuospatial and sensorimotor stimuli are the body's early warning system for potentially noxious stimuli (Lloyd et al., 2006).

Using fMRI to study pain empathy, Singer et al. (2004) found that the same brain areas were activated when both the participant and a loved one (as signaled) experienced pain. The authors noted that empathic experience did not involve the whole pain network, only those parts involved in affective qualities (bilateral AI, rostral ACC, brainstem, and cerebellum), but not sensory regions (posterior insula, caudal ACC, secondary somatosensory cortex, and sensorimotor cortex) specific to receiving pain (Singer et al., 2004). Another study found that pain recognition, while necessary for pain empathy, is independent of it. Using an RT paradigm go/no-go task to study vicarious pain responses, Morrison, Poliakoff, Gordon, and Downing (2007) found that pain observation modulated the motor system by speeding withdrawal actions and slowing approach behaviors. The study revealed a basic mechanism for using visual information to prepare appropriate behavioral responses. Brain regions involved included dorsal anterior and mid-cingulate cortices, and adjacent supplementary and pre-supplementary motor areas (Morrison, Poliakoff et al., 2007). A follow-up fMRI study confirmed that medial premotor regions were involved in pain empathy (Morrison, Peelen, & Downing, 2007); and that pain observation activated ACC, mid-cingulate cortex (MCC), and the AI. Supplementary and pre-supplementary motor areas were also involved in acute pain processing and action selection. Both affective content and behaviorally relevant information influenced motor responses. Different areas of the cingulate cortex (dorsal ACC, MCC, PCC) tracked combinations of noxiousness of threat (e.g., implement), potential or actual contact with own or others' body part/s, and linked this information with response preparedness (Morrison, Peelen et al., 2007).

In an earlier fMRI study of the paradox of sympathy, Morrison, Lloyd, Di Pellegrino, and Roberts (2004) sought to answer questions like: "How are observed and felt states related?" and "Why do we care about pain to another?" The authors found common activity in response to noxious visual and tactile stimuli in the right dorsal ACC, suggestive of a shared neural substrate for felt and observed pain for aversive events. The primary somatosensory cortex was activated in response to noxious (and innocuous) tactile, but not to visual stimuli. The ACC codes the motivational-affective dimension of pain, which is associated with preparatory behavioral response to aversive stimuli. The vicarious pain effect operates independently of whether the other person is known to the observer. The ACC is also involved in motivation, emotional and social behavior, and response selection, while other regions of the dorsal ACC are implicated in attention and arousal, particularly related to response preparation (Morrison et al., 2004).

Contemporaneous studies exploring neural correlates of danger perception and cognate topics represent the early stages of obtaining experimental neural and sensory confirmation of cognitive models proposed at least since the 1980s. For example, Witt and Sugovic's (2013) finding that object threat and perceiver's blocking ability acted independently appear to reflect the factors in Slovic and colleagues' orthogonal dimensions of dread risk and intervention ability in a number of psychometric paradigm studies. Brain imaging studies of pain empathy have revealed that pain observed in others is an important motivator. In evolutionary terms, there would be adaptive advantage in being able to assess others' emotional (e.g., fear) and physiological (e.g., pain) states rapidly and accurately to increase the likelihood of effective action preparation. However, terrorist groups can use this intuitive knowledge to enhance fear of terrorism in a massive audience, for example, by releasing video footage of beheadings and other brutalities, knowing that accounts of this behavior will be extensively broadcast by international media. This salient exposure is then likely to enhance the perceived risk of terrorism globally.

Evolution has also primed us to be very aware of possible threat from certain facial characteristics. In an fMRI study of face perception and trustworthiness, Freeman, Stolier, Ingbretsen, and Hehman (2014) found that the amygdala responded to assessed trustworthiness of a face even before it can be consciously perceived (i.e., processed subliminally at ~33 ms). Thus, pre-conscious sensation operates conjunctively with danger perception. The authors suggested that the pathway responding to threat-relevant stimuli was retino-collicular-pulvinar, although the amygdala may respond to very simple cues such as enlarged eye whites in fearful expressions (Freeman et al., 2014). However, while there might be some overlap with emotional expressions (e.g., anger), trustworthiness was more complex to assess, and while multiple potential routes existed, the ventral temporal cortex was identified as the most likely processing route where detailed facial information can be extracted. Once conscious perception is involved, faces are processed in the visual-ventral stream in the fusiform cortex, while cortical-subcortical feedback loops are also critical to awareness (Freeman et al., 2014).

Emotions such as fear, disgust, or anger, can serve as alarm signals, either in response to a direct threat (e.g., rapidly approaching vehicle) or in mirroring another's facial expression, acting to direct attention toward the threat and to promote an appropriate motor response. Driven by evolutionary survival needs, threats of interpersonal violence and infectious disease transmission can lead to fear prejudice against out-group members, particularly under conditions where personal harm is perceived to be likely, so that out-group prejudice becomes a threat management mechanism (Schaller & Neuberg, 2012). Perceived social threats might include those to a group's economic resources (e.g., job loss), or ego threats to individuals' self-appraisals. Emotional response mechanisms mean that angry faces of male out-group members are particularly likely to be remembered by in-group males (Schaller & Neuberg, 2012).

4.3 Risk and emotion

Fear has been defined as a lack of situational control and uncertainty (unknown risk), while anger has been defined by a lack of individual control (dread risk) and uncertainty. Using the Asian disease scenario framing narrative, Lerner and Keltner (2001) adopted the appraisal-tendency hypothesis to explore experimentally induced and dispositional negative emotions. Risk estimates, operationalized as risk perception (RP), were driven by both the controllability (dread dimension) and un/certainty (unknown dimension). Fear and anger had opposite effects on RP, such that fear generated pessimistic risk estimates and risk-averse choices, while anger induced optimistic risk estimates and risk-seeking choices (Lerner & Keltner, 2000). Happiness (elevated certainty and individual control) reduced risk aversion, while anger was closer than fear was to happiness. While certainty and control appraisals moderated emotion effects, the authors pondered the possible impact of cultural effects on emotional aspects of decision making (Lerner & Keltner, 2001).

The Carmel forest fire (Israel, December 2010) was the case study used by Shavit, Shahrabani, Benzion, and Rosenboim (2013) in a between-groups survey exploring different appraisals of uncertainty. The theoretical framework included a valence approach, the appraisal-tendency framework, and risk amplification. The valence approach predicts that fearful and angry people will make pessimistic risk assessments. The appraisal-tendency framework states that anger and fear exert different influences on personal risk assessment. The authors found that while fear was greater in those closest to fire compared with those further away, anger levels were the same. Compared with men, women had higher RP and higher fear. Fearful people reported higher perceived self-risk, including for risks unrelated to the fire (e.g., motor vehicle accident). The generalization effect occurs as fearful people perceive greater risk in new situations as they assume uncertainty and lack of situational control. Compatible with a valence approach, fearful and angry people made pessimistic assessments in the face of unambiguous events (Shavit et al., 2013).

Using fMRI/sMRI to study novice skydivers' cortical (PFC) thickness, and dispositional influences (state/trait anxiety using the STAI) and sensation seeking (SS), in a signal detection (threat perception) task, Mujica-Parodi, Carlson, Cha, and Rubin (2014) incorporated affect valence. In exploring the role of emotion in risk recognition, including fear and resilience, the authors measured stress hormones (cortisol, epinephrine, beta endorphin, and testosterone). It was revealed that high SSs were less anxious when challenged, and showed blunted physiological (cortisol, startle) and neurobiological (PFC, amygdala) responses, as well as devaluing aversive outcomes. While a well-regulated neural circuit reacts to a threat and returns to normal when a threat dissipates, individuals with unbalanced regulation between excitatory (amygdala) and inhibitory (hippocampus, PFC) neural circuits had lower cortisol and anxiety responses to risky situations (e.g., skydiving) and less accurate threat perception. The inhibitory circuit comprises the inferior frontal gyrus (IFG), the dorsomedial prefrontal cortex (DMPFC), insula, amygdala, and hippocampus. The excitatory regulatory circuit comprises the ACC and amygdala. Impaired control was localized in the IFG, which is concerned with affect processing, emotion suppression, and response inhibition, and may play a role in threat assessment. A structural equation model (SEM) showed that SS was mediated by threat perception, which was mediated by neural reactivity, cortisol level, and regulatory balance (Mujica-Parodi et al., 2014). The authors concluded that while the brave felt fear, they were able to overcome it (adaptive response), but the reckless failed to recognize danger and were, therefore, less likely to mitigate risk (maladaptive response).

4.4 *Fear and risk perception*

Fear has been described as a psychological trait representing an adaptation to danger (Dolan, 2000). Detecting and responding to danger is fundamental to survival. While humans' contemporary lifestyle presents limited dangers from other species, our constructed world has created numerous other dangers, including environmental hazards, and intraspecies (conspecific) aggression. Our extensive capacity for remembering, thinking about, and imagining a plethora of possible events can activate our attentional and fear circuits through internally generated cognitive and emotional processing (Labar & LeDoux, 2001).

Therefore, accurate perception of risks becomes increasingly critical in terms of minimizing two types of errors: (1) identifying a hazard that is either nonexistent, or that has a very low probability of being realized, and (2) failing to detect a hazard with a high occurrence likelihood. Some examples of both error types are in Summary Text 4.2. While our hard-wired threat detection and response system is generally well adapted to identifying ancestral threats (e.g., from predatory species), extensive learning may be required to appraise and respond appropriately to contemporaneous hazards (e.g., vehicular traffic). Such learning may occur through various forms, including processes involving associating an unconditioned (threat) stimulus with a conditioned stimulus (e.g., alarm). Details of the operation of this process are described elsewhere (e.g., Armony & LeDoux, 2000; Labar & LeDoux, 2001). As well as the cortex, amygdala, thalamus, and hypothalamus, key components of the fear system include the dorsal vagal complex, brainstem structures (e.g., NST), and visceral organs (Porges, 1998).

A fundamental emotion, fear is a frequent and normal reaction to some dangers, and has been described as the conscious experience of danger (Labar & LeDoux, 2001).

SUMMARY TEXT 4.2 Two Types of Risk Misperceptions

Disbanded in 2008, the United Kingdom's Risk and Regulation Advisory Council was established to identify official over-reaction to risks and to mitigate excessive reaction to minimal risks, for example, through regulation in response to relatively low-likelihood events that might be amplified by the media and thereby gain rapid salience. An example might be the relatively trivial risk of people being harmed by falling trees or branches (Ball & Watt, 2013). Other examples have included government responses to swine flu and foot and mouth disease among farm animals, which have prompted large-scale slaughter of healthy animals deemed to be at risk. Multiple passenger deaths in dramatic incidents, such as rail crashes, have particular salience and frequently generate mitigating action at the expense of addressing much larger numbers of single deaths that arise through trespass and suicide on rail property, which tend to be seen as the victim's fault and thereby undeserving of the same degree of intervention. In the year following the U.S. September 11, 2001 terrorist attacks, it was estimated that so many people avoided airline travel by driving that an additional 1500 deaths on U.S. roads resulted (Spieglhalter, 2009). However, reduced global air travel in the months following the 9/11 attacks delayed the start of the flu season, so that an unknown number of lives might have been saved by avoiding the flu.

Risks arising from distractions from using various in-vehicle technologies, including hands-free cell (mobile) phones, texting, touchscreens, and voice-activated systems, result in thousands of casualties annually, including numerous fatalities. Some jurisdictions, for example, in Australia, the United Kingdom, and the United States, have banned handheld mobile devices by drivers of moving vehicles. However, despite considerable scientific evidence of the dangers of drivers using such devices to themselves, their passengers, and other road users, legislation and enforcement has been virtually nonexistent in combating even the well-documented dangers of hands-free cell phones, let alone more recently available technology-driven in-vehicle devices (Strayer et al., 2013). This is an example of a serious high-risk activity that governments have been, and continue to be, very slow to address.

An effective form of learning, fear conditioning can be acquired within a single exposure and is often very difficult to extinguish (Armony & LeDoux, 2000). Disorders of the fear system include panic attacks, phobias, generalized anxiety, and post-traumatic stress disorder (PTSD). Receiving inputs from cortical and thalamic sensory processing regions, by determining whether stimuli processed through these channels represent potential danger, the amygdala is central to experiential fear. Armony and LeDoux (2000) explained the key role of the amygdala in fear processing in detecting danger and activating arousal systems to influence subsequent selective sensory processing. The amygdala's critical role in processing sensory stimuli that signal fear extends to adaptive learning with respect to a previously neutral stimulus that becomes associated with a fearful stimulus (Dolan, 2000). While the amygdala receives inputs from late cortical sensory processing stages, because it projects back to the earliest stages, once activated by a sensory event (e.g., an oncoming vehicle) via the thalamo-cortical pathways, it can begin to regulate the cortical areas that project to it, thereby controlling its sensory input. Through its projections to various arousal networks, including the basal forebrain and brainstem cholinergic systems, and the locus coeruleus (LC) noradrenergic system, which innervate distributed cortical regions, once it detects danger the amygdala also indirectly influences cortical sensory processes (Armony & LeDoux, 2000). Neural systems associated with sensation and perception that interact with the fear network include attention, declarative memory, implicit memories (e.g., for emotions), and consciousness (Armony & LeDoux, 2000).

The amygdala receives input from both fast (thalamic) and slow (cortical) pathways. The thalamic pathway provides a rapid immediate reaction and a basis for differentiating dangerous from nondangerous stimuli. The cortical pathway, involving memory regions, more accurately determines the validity of an emotional response to a sound or other stimulus. A rapidly generated fear response is maintained and reinforced through a network of connections that associate specific sounds with danger, including the amygdala, the auditory cortex, and the hippocampus (Horowitz, 2012). Sounds associated with negative emotional responses tend to be perceived as louder than those without such associations. Sounds with the strongest emotional responses are human vocalizations. These, and sounds from animals about our own size, are easiest to hear, as they stimulate the auditory system in its most sensitive region (Aeschlimann, Knebel, Murray, & Clarke, 2005; Horowitz, 2012). Sound acts as a "natural warning" at all neural levels (Horowitz, 2012). Generic sound characteristics from evolutionary biology include

1. Loud and low-pitched—Frightening
2. Loud with many random frequencies and phase components (e.g., fingernails drawn down a blackboard)—Annoying
3. Loud and inescapable—Confusing and disorienting
4. Out of context (e.g., from nonnormal source)—Disorienting and frightening

The most effective acoustic warnings (or weapons) would combine these four elements (Horowtiz, 2012).

Reporting a dissociation between attention and awareness, and demonstrating specific attentional effects for spatial location, Lin, Murray, and Boynton (2009) found that a looming object on a collision path with an observer captured attention even though it was perceptually indistinguishable from an equivalent stimulus that would just miss the observer. Thus, the spatially selective detectors of our automatic attentional process are more sophisticated than a simple general threat-detection mechanism (Lin et al., 2009). Consistent with a center-of-mass model of relative threat assessment, looming stimuli from the six o'clock position appeared to have the most threatening direction of motion (Lin et al., 2009). Three possible mechanisms for which evidence existed for how attention might operate without awareness proposed by Lin et al. include: (1) cues might influence attention due to contingencies between a cue and target that an observer was unaware of; (2) a target might be processed more effectively because of being attended to when an observer was unaware of this; and (3) attention might be directed by cues that an observer was unaware of. Thus, contrary to traditional salience-based models of attentional capture, without perceptual awareness, the visual system can extract relevant information to automatically distinguish threatening from nonthreatening stimuli at a level of precision independent of our conscious perception (Lin et al., 2009). Detection of threatening stimuli (e.g., of snakes, spiders, angry/fearful faces) occurs more quickly than for neutral stimuli in children (at least from 3 years of age) as well as in adults (LoBue, 2014). An issue that then arises is whether threatening information that automatically prioritizes attention relies on neural processes distinct from those activated during conscious perception.

Selective attention arising in cortical regions enables us to allocate processing resources to task-relevant stimuli at the expense of task-irrelevant stimuli. The direct attention-independent thalamo-amygdala pathway is critical to our ability to detect and respond to threats arising outside our current attentional focus. From an evolutionary perspective, reacting unconsciously to a predatory attack would be more adaptive than the relatively time-consuming conscious process of predator identification. Further supporting the well-established dual-processing model of visual attention (Milner & Goodale, 2008), unconscious action in directing attention to the location of a potential threat, for example, in response to a looming stimulus, has been found to be more accurate at calculating an object's path of motion than the conscious perception pathway (Lin et al., 2009). By reducing the complexity of stimulus input, attention corresponds with the dorsal orienting vision-for-action channel (Milner & Goodale, 2008), while consciousness has been linked with the ventral vision-for-perception pathway (van Boxtel, Tsuchiya, & Koch, 2010).

Proposing a fear conditioning network integrated with a selective attention model, Armony and LeDoux (2000) identified asymmetrical competition for limited processing resources such that fear reactions can interrupt behavior to favor danger-elicited survival responses. Within this model, emotional processing can operate independently of, and modulate the focus of, attentional mechanisms. Thus, when required, the amygdala can direct attention toward dangerous stimuli, or stimuli that are potentially dangerous or that represent danger (e.g., signals or alarms). Mediated by medial temporal lobe system input, the amygdala also plays a role in consolidating declarative memories with affective content (e.g., fear), which are more vivid and longer lasting than memories without emotional content (Armony & LeDoux, 2000). The amygdala also links these processes with the stress response, which is considered in Chapter 6. The role of (in)attention in human error is explored further in Chapter 5.

An extreme example of a fear-driven response to real or imagined threat is behavior represented by so-called doomsday preppers who devote extensive personal resources, including engaging family members and associates, to developing elaborate defenses against perceived widespread threats that might include nuclear war, social or economic breakdown, infrastructure collapse, or extreme weather events. As well as having a fear- or anxiety-driven component, these behaviors might be reinforced by media messages or personal experiences that provide supposed evidence for the validity of the behavior through operation of the confirmatory bias. Those engaging in these preparations might be compared with the celebrated doomsday group studied by Festinger, Riecken, and Schachter (1956). The central dilemma posed by such behaviors is to maintain a balance between awareness of a variety of potential threats without sacrificing the ability to live your daily life relatively free from fear or anxiety.

The role of the human amygdala in appraising threats extends beyond immediate danger detection as it orients our attention to gather critical information to assess the threat. The threat could be represented internally, for example, from degraded air quality, a heart attack, or other urgent medical condition that triggers a reaction in our interoceptive sensory system. As well as the amygdala, other brain circuits likely to be activated in the threat appraisal process include memory circuits, parts of the hypothalamus, and the periaqueductal gray (Gross & Canteras, 2012). It has been suggested that, as well as playing a critical role in risk perception, a functioning amygdala is required for PTSD to develop. While humans can sense many sounds of different qualities, we are rarely able to hear sounds generated by our own bodies, which means that we cannot usually detect our own heartbeat, or a myriad of other sounds that might presage important changes in our physiology or metabolism, perhaps warning signals of danger. The common evolutionary basis for threat or risk assessment in humans and other animals is described in Summary Text 4.3.

Types of fear memory include: contextual fear conditioning (a form of associative memory), fear memory system, fear reconsolidation, fear extinction, instrumental fear learning, and declarative memory modulation by emotionally relevant stimuli (Schafe & LeDoux, 2004). Learned fears guide the acquisition of behaviors to avoid danger. Fear can augment the strength of memory formation for significant life events. In classical (Pavlovian) fear conditioning, or associative pairing, an initially neutral stimulus is paired with an aversive event (unconditioned stimulus) to create a fear for the previously neutral stimulus (e.g., a tone). The acoustic startle response may be involved. Effector systems translate an external threat into various fear responses, including defensive behavior, autonomic arousal, hypoalgesia, reflex potentiation, and release of stress hormones (Schafe & LeDoux, 2004). Instrumental fear learning is required to actively or passively avoid danger.

Interacting extensively with brain systems involved in cognition and awareness (Phelps, 2004), the amygdala influences cognition and awareness by alerting memory retention through arousal, as well as facilitating attention and perception. The left amygdala (and the startle reflex) is also involved in the expression of instructed fear (e.g., telling someone not to touch a live section of apparatus, or that a particular dog might bite), which depends on neural systems underlying language (i.e., left hemisphere) and episodic (declarative or explicit) memory. Awareness is necessary for instructed fear learning, that is, the stimulus must be directly or vicariously sensed or perceived. Cognitive fears may be imagined or anticipated, even if not actually experienced (Phelps, 2004). This issue is explored further in Chapter 6 on stress and coping.

While false memories have traditionally been considered as undesirable (e.g., in eyewitness testimony), Howe, Garner, and Patel (2013) explored the possibility of an adaptive function for false memories ("memory illusions") that are primed for danger, threat, and survival. In an experimental study, as well as recalling more survival-related words, child and adult participants found such words to be more useful than neutral false memories for solving related puzzles (Howe et al., 2013). The authors suggested that memories for survival-related knowledge tended to have a higher degree of connectedness, and therefore threat-related valence (e.g., terms like *battle, death, injury, struggle, virus*), than less evidently adaptive information. By this interpretation, at least some false memories are predicated on a powerful reconstructive memory system designed to enhance an organism's likelihood of survival and success. An example similar to that provided might be an individual incorrectly remembering a predator (e.g., aggressive person) while in a particular location compared with another person correctly remembering only signs of aggressive behavior

SUMMARY TEXT 4.3 Risk Assessment as an Evolved Threat Detection System and What May Go Wrong

As a core generalized process for detecting and analyzing threats, some form of risk assessment (RA) has evolved in all prey species for determining the most appropriate response(s) in a given set of circumstances (e.g., freeze, flee, defensive threat, or defensive attack) as a reaction to danger (Eilam, 2005). A highly sophisticated process, RA is particularly required when a potential threat is ambiguous or complex (perhaps requiring the orienting response), in evaluating defensive behaviors adopted (involving learning and memory), and in determining when a threat is no longer present (and when normal behavior can be continued). When presented with a variety of conspecific threat scenarios, remarkably highly correlated common patterns of responding have been found for human participants in different cultures as have been identified in various infrahuman species (Blanchard, Griebel, Pobbe, & Blanchard, 2011).

Humans' RA has been associated with neural activation patterns corresponding with those identified in other species. These include a hypothalamic "medial defense zone" (MDZ) involving connectivity between anterior, ventromedial, and dorsal hypothalamic nuclei. Input to the MDZ is from the amygdala's medial, basolateral, and lateral nuclei, the stria terminalis bed nucleus, hippocampus, and lateral septum, with output via the periaqueductal gray (PAG). While the amygdala's role is for threat detection, with appropriate reference to prior experience with painful stimuli, the hippocampus and lateral septum provide contextual information on potential threats (Blanchard et al., 2011). While flight/escape responses have been linked with activity in the basolateral amygdala and dorsal PAG, projections from the MDZ to thalamic nuclei (e.g., medial, paraventricular) involved in responding to predator attack link with cortical areas associated with planning defensive behaviors. Specific brain regions are involved in freezing and flight responses, while inhibitory interactions between structures mediating defensive actions allow for rapid switching between defense modes (Eilam, 2005). Corresponding human neural structures involved in RA processing and motor function (e.g., for flight or attack), include the VMPFC, hypothalamus, hippocampus, amygdala, mediodorsal thalamus, right striatum, right insula, and dorsal anterior cingulate gyrus (Blanchard et al., 2011).

Humans' highly adapted RA system may be subject to variation from its prime function. For example, the striatum has been linked with obsessive compulsive disorder (OCD), indicative of OCD-related behaviors being associated with aspects of RA and defense. Rumination has been identified as a variant RA response to various conditions or situations, and has been linked with generalized anxiety disorder. Different variations have been associated with panic disorder. Dorsal columns of the midbrain PAG, as well as being pivotal to the flight response, are also involved in panic attacks (Blanchard et al., 2011).

Mirror neurons, which activate when either an individual or an observed other performs an action, have a role in situational differences analyzed in RA. One study revealed that about 50% of the mirror neurons responded to the distance (e.g., from a threat) over which an individual was capable of acting and potentially controlling a situation, while a subset of these neurons reacted quickly and appropriately to distance changes. It has been suggested that in the context of a potential threat, the mirror neurons' role is to determine whether an action that is functional with respect to a desired outcome (e.g., responding appropriately to a threat) can be completed successfully (Blanchard et al., 2011). This function corresponds with the psychometrically well-documented controllability dimension of risk perception. Mirror neurons are also critical in identifying others' emotions from body posture, and particularly from their facial expressions. Within the context of a potential conspecific attack, an individual's RA includes assessing the likelihood of attack from another person by reading their demeanor (Blanchard et al., 2011).

An evolved adaptive survival strategy, tonic immobility (TI), as distinct from an initial freezing reflex response, may be activated once an animal has been captured or when capture is imminent, and when TI appears to offer better survival likelihood than fighting a predator. Comprising abrupt onset profound but reversible physical immobility and muscular rigidity, TI comprises a largely involuntary behavior pattern involving sympathetic and parasympathetic responding. Unlike learned helplessness (a learned response), TI is an unlearned response, although neither learning, nor memory, nor alertness, nor consciousness, are disrupted during TI (Marx, Forsyth, Gallup, & Fusé, 2008). Two essential components of TI are intense fear and perceived restraint or entrapment, which are also features of PTSD. TI equally applies to humans as to other species—such states being characterized as "scared stiff" or "frozen with fear." Unlike volitional responses to predation, TI is an action of last resort and not a preferred strategy, and is likely to be a frightening experience in itself. TI can also be associated with long-term distress and impairment, as in PTSD. Many experiences might precipitate TI in humans, including predator (including conspecific) attack, motor vehicle and airplane crashes, military combat, and physical and/or sexual assault. While there may be substantial individual differences (IDs) in response to extreme situations, for example, based on previous experiences, fearing for their life many victims may feel numb and be unable to vocalize to alert others to their plight. Controllability is one ID affecting the extent to which an IT response is generated, while a loss of sense of self or dissociation is another recorded feature. However, there is an acute awareness of the immediate environment to detect signals that might offer escape opportunities (Marx et al., 2008).

Humans' (and other species) defensive behaviors have been identified as fundamentally two-dimensional. The first dimension relates to defensive distance, which is mapped onto neural levels with the shortest defensive distance involving the lowest neural level (PAG), and the largest defensive distance involving the highest neural level (PFC). This feature corresponds with the well-documented cognitive controllability psychometric dimension. The second dimension extends from fear to anxiety, and is mapped onto separate parallel streams across the first dimension so that fear and anxiety can be represented at all neural levels. This feature corresponds with the well-documented "dread" or emotional dimension identified in psychometric studies. In nontypical forms, it can also be associated with stress disorders, such as panic attacks, obsessions, and phobias (Eilam, 2005).

(e.g., property damage) in that location (Howe et al., 2013). Because the person with the false memory described would subsequently be more likely to behave cautiously in the same location, their survival likelihood over the individual who correctly remembered only property damage would be likely to be enhanced in the event that an actual potential predator was present. An actual example of such cautious behavior, as related to one of the authors, is described in Summary Text 4.4.

SUMMARY TEXT 4.4 Case Example Illustrating Cautious Survival-Oriented Behavior in the Face of Potential Threat

A woman and her son were walking in a quiet residential dual carriageway street at around 3:00 p.m. when the woman saw two young males approaching them at a distance of around 35 m. Alerting her son to the males' behavior, the pair continued walking while pretending not to pay attention to the two males, who briefly communicated before splitting up near a parked car, which they walked around while pretending to look in each of the car's windows. At a distance of a few meters from one of the young males, the woman had the feeling that the young man was trying to distract her to also look into the vehicle and was immediately alerted to the possibility that she could be robbed. With about a second to make a decision, the woman's instinct told her to run, so that she and her son ran down the street away from the young males.

After some 50 m, the woman turned a round to see her son some 2 m behind her and the two males running in their direction. Feeling scared the woman continued to run and seeing a female walking toward her ran in the female pedestrian's direction. Rapidly assessing the scene, the female pedestrian also began to run and escaped down a nearby passageway that was unknown to the mother and son. Already out of breath and feeling her stomach cramped, the woman reached the end of the quiet street and made her way into a main street with busy traffic in which a familiar bank was located within 100 m or so, on the opposite side, which became her immediate refuge target. However, crossing the main street was made difficult by partial road closure and temporary barriers erected for construction work. At the junction, two uniformed rail workers appeared in quick succession and other pedestrians were also in the vicinity. After taking some 30 seconds to catch her breath, which despite never having suffered from any respiratory complaint she could now hear very loudly, and feeling physically unwell, the woman and her son crossed to the safety of a shopping mall that they knew well.

In the shopping mall, it took some 30 minutes for the woman's breathing to return to normal, while her stomach remained cramped and hard for several hours. Her digestive system was not functioning properly during her evening meal and over the next two nights she had nightmares, awakenings, and continued stomach cramps. Reflecting on the events, the woman considered that her protective actions with respect to herself and her son had been correct and had prevented her from being robbed and assaulted. It may be pertinent that the woman had been robbed on a different street in another country by a young male some 20 years previously, during which the assault she had sustained serious injury. When deployed for action in similar circumstances, the memory for such events can be highly adaptive.

4.5 Functionality of biased perception for action in response to threat

Proposing the threat-signal hypothesis to explain why people feel threatened by some stimuli, Cole, Balcetis, and Dunning (2013) proposed that individuals will misperceive a stimulus, for example, such that it appears larger or closer than nonthreatening stimuli evoking equally strong negative affective responses (e.g., disgust). An evolutionary frame provides a generic rationale for all perceptual biases that improve an organism's likelihood of survival and success. When rapid action is required, either to address a threat (e.g., an aggressive person nearby) or to pursue a desired goal (e.g., to satisfy hunger, thirst, or sex needs) then biased perception for action should help to regulate emotions, cognitions, and behaviors to assist in achieving current goals (Cole et al., 2013). As well as increasing sympathetic nervous system activity, leading to elevated heart rate and blood pressure, and cortisol release, threats increase activity in subcortical brain regions associated with reflex-action preparation and defensive behavior (Pichon, de Gelder, & Grèzes, 2012).

4.6 Individual differences

In testing the threat-signal hypothesis, Cole et al. (2013) found that individual differences in affective experience of threat predicted differences in perceived proximity to the source of the threat. Fear states also generalized to influence perceptions of some unrelated stimuli. Identifying attention as a potential mechanism for perceptual biases, Cole et al. (2013) revealed that threat exerted a disproportionate effect on attention, which influenced environmental properties associated with the threat, including its size and distance from the observer. The cognitive process involves a threatening stimulus capturing and narrowing the scope of visual attention to influence size and distance perception. Our perceptual system is thereby biased to promote beneficial action and successful navigation of our environment (Cole et al., 2013).

Various ID influences have been researched in connection with risk DM and engagement in risky behaviors. In a meta-analysis (24 studies) examining birth order as a risk influencer, Sulloway and Zweigenhaft (2010) adopted an EP perspective to consider athletic ability, particularly in baseball. EP predicts that siblings compete differentially for parental investment and that diversification and risk-taking (R-T) are adaptive when survival chances or reproduction are constrained—as for laterborns. An important role in human evolution has been revealed for SS (Posner & Rothbart, 2009). Sulloway and Zweigenhaft (2010) found that laterborns were (1.5×) more likely than firstborns to participate in dangerous sports and to engage in riskier moves in baseball. Possible reasons for the finding that laterborns were higher on SS and related personality traits (e.g., extraversion) included: (1) childhood niche hypothesis (laterborns' personalities develop differentially to reflect parental investment), (2) biased learning trajectory (childhood differences result in laterborns being more adept at judging when R-T is appropriate, which leads to risk preferences being adaptive in later life), and (3) ongoing rivalry hypothesis (some adult behaviors continue to be sensitive to sibling competition), which was favored by Sulloway and Zweigenhaft (2010). In considering the role of genetic and environment (specifically parenting) direct and interaction effects, Posner and Rothbart (2009) discovered that a genetic basis for R-T and impulsivity existed in a seven-repeat allele of the DRD4 gene. Higher quality parenting meant that children with this allele showed normal R-T, but children with this allele combined with lower quality parenting showed very high values for R-T (Posner & Rothbart, 2009).

Other studies have provided further evidence for individual differences in threat perception, for example, finding that spider-phobic individuals perceived spiders to be larger than nonphobic controls did (Vasey et al., 2012). The generalizability of phobias as a heightened threat-detection system can lead sufferers to be more likely to interpret ambiguous stimuli as threatening, pointing to a fear-based distortion of encoding and processing of a variety of perceptual information (Vasey et al., 2012). The precise nature of the interplay between affective (particularly fear) and cognitive (particularly memory of fearful encounters) elements remains to be disentangled. It is possible that biased perceptions might increase fear, while memory distortions might result from fearful encounters (of the "If I feel this anxious, then the spider must have been huge" variety). Perhaps a cycle is established whereby cognitions (especially, attention and memory) and fear reinforce each other to maintain a high level of threat response (Vasey et al., 2012).

Comparable findings were evident from Stefanucci, Proffitt, Clore, and Parekh's (2008) study of observers' estimates of the steepness of a hill, which was found to be greater when positioned in a relatively more hazardous situation at the top of the hill (standing on a skateboard) compared with a safer position (standing on a box with the same dimensions). Self-reported fear was also associated with steepness of hill ratings. However, visually-guided steepness ratings were affected neither by positional nor by dispositional effects (Stefanucci et al., 2008). Visual distortions of building height were evident in Stefanucci and Proffitt's (2009) study in which vertical distances were greatly exaggerated, particularly when viewed from the top of a high building. That height overestimation might be due to dispositional effects was confirmed when it was found that overestimation of size and distance was associated with both trait- and state-level fear of heights (Stefanucci & Proffitt, 2009).

To determine whether perceptually exaggerated threats (bigger, higher, closer, longer duration, more intense, etc.) could be countered, Harber, Yeung, and Iacovelli (2011) tested the resources and perception model, which maintains that psychosocial resources can lead to a more accurate perception of the risk. The authors found that induced self-worth moderated the perceived closeness of a threat (a live tarantula). In a second study, the authors showed that greater self-esteem reduced perceived height when observers were prevented from holding a guard rail when looking down from a height. It was concluded that psychosocial resources can replace physical resources to moderate perception of height and distance components of a threat, and that different resources can have comparable moderating effects (Harber et al., 2011). In popular culture, these psychosocial resources might be interpreted as courage or bravery.

4.7 Role of emotions and framing in risk-related decision making

Affect in decision making (DM) can counter cognitive-consequentialist explanations for DM (e.g., expected utility theory—EUT, mood maintenance hypothesis—MMH). Maintaining that emotional reactions often drive behavior, the risk-as-feelings hypothesis (RAFH) identifies anticipatory emotions (e.g., fear, dread, anxiety, worry) as immediate visceral reactions to risks and anticipated emotions as future projections (Loewenstein, Weber, Hsee, & Welch, 2001). While being similar to the somatic marker hypothesis (anticipatory emotions), the affect-as-information perspective, and the affect heuristic, which see emotions as input to DM, RAFH differs in that outcomes might diverge from what individuals see as being in their own best interests. While trait anxiety is associated with risk aversion, RAFH maintains that anticipatory emotions are crucial for good risk-related DM (Loewenstein et al., 2001).

Seeking to account for the greater explanatory power of RAFH and related models (e.g., affect heuristic) over risk-as-analysis (rationality) models, in establishing a link between smoking and cancer risk, Slovic, Peters, Finucane, and Macgregor (2005) considered the role of RP and risk appraisal (RA). Dual process models contrast the emotional context for DM as intuitive (System 1—e.g., affect heuristic) with the rational (System 2) process. Reviewing the history of the role of affect in RP and risk DM, particularly dual-process models, Slovic et al. (2005) maintained that the experiential system (based on intuition, gut-feeling, etc.) predominated during human evolution, while analytical tools have been developed to boost the more contemporaneous rational approach to risk DM. However, affective reactions continue to serve as orienting mechanisms for rapid DM and presentation of affect-laden material is very influential (Slovic et al., 2005).

Decision makers base their decisions partly on the emotions they expect to experience in response to decisions outcomes. Future anticipated negative emotions (regret, disappointment), as a result of DM, were considered by Zeelenberg, van Dijk, Manstead, and van de Pligt (2000) within the context of decision theory and expectancies. Considering emotion as the primary driver of decisions, regret was appraised as being more associated with self-agency, while disappointment was appraised as being related to other-as-agency. This was interpreted as regret being essentially related to personal choices, while disappointment reflected a state of the world. Thus, while risk aversion may avoid disappointment, it may also enhance the likelihood of later regret (Zeelenberg et al., 2000).

The general framing effect identifies loss-framed outcomes as mainly leading to risk-seeking outcomes, while gain-framed outcomes are more likely to result in risk aversion. However, there is likely to be a number of ways in which DM is contextualized that are liable to influence whether a decision is destined to be risk-seeking or risk-averse. For example, frequencies (e.g., expressed as number of times an event occurs in 100) have been revealed as a more powerful framing device than percentage likelihoods in generating risk-averse DM (Slovic et al., 2005). The emotional priming paradigm provides one way of explaining the effect of emotion on DM. By reducing aversive aspects of sure loss, Cassotti et al. (2012) found that exposure to emotionally pleasant stimuli neutralized whether a presentation was framed in terms of gain or loss. While a positive emotional context did not influence R-T behavior, it did decrease risk propensity in the loss frame. Cassotti et al. (2012) confirmed that a positive emotional context can reduce loss aversion and reinforced the dual-process view that a framing effect stems from an initial evaluation based upon a System 1 affect heuristic (Cassotti et al., 2012).

From a neuroeconomics (prospect theory, subjective utility, framing) and affect generalization theory perspective, Hu, Wang, Pang, Xu, and Guo (2015) experimentally addressed the role of time pressure and emotional valence on risk DM. It was revealed that compared with negative emotions, a positive emotional state rendered participants more risk prone. Compared with no time pressure, time pressure led to greater risk seeking, and high time pressure also polarized the effects of different emotions. Of the two cognitive pathways operating in DM, when deeper, more complex cognitive processes were blocked by time constraints, participants primed with negative emotionality exhibited a dramatic decrease in risk-seeking, while leaving unchanged the DM of participants primed with positive emotion (Hu et al., 2015).

Experimental evidence using the Balloon Analogue Risk Task (BART) and Iowa Gambling Task (IGT) was available from Heilman, Crişan, Houser, Miclea, & Miu (2010), who considered the critical role of emotion regulation (ER) in risk DM. Principal ER strategies include cognitive reappraisal (CR), which consists of reformulating the meaning of a situation, and expressive suppression (ES), which acts to inhibit behaviors. CR of induced fear and disgust promoted risky decisions (reduced risk aversion) in BART, and was associated with better performance in the IGT pre-hunch/hunch period, with the effect occurring via the emotional route. While natural negative emotions also increased risk aversion in BART, the effect was modulated by CR of emotions. Reducing emotional experience from CR had beneficial effects on DM (Heilman et al., 2010). Both CR and ES decreased the expression of positive emotions, but only CR was effective in reducing the experience of negative emotions (e.g., anger, embarrassment). It was concluded that ER affected DM under risk and uncertainty by reducing the experience of emotion, while appraisal of control mediated the relationship between emotions and R-T. At a neural level, the amygdala and ventromedial prefrontal cortex (VMPFC) were involved in reappraisal and anticipating the emotional impact of DM, while the insula and nucleus accumbens (NA) were also involved. While emotion is critical in DM, PFC-amygdala circuits supported optimal DM under risk and uncertainty (Heilman et al., 2010). Studies investigating the framing effect and the role of emotions in DM are described in Summary Text 4.5.

As a threat-detection and potential survival mechanism, humans are evolutionarily primed to respond rapidly and appropriately to expressions of fear on others' faces. Brain areas implicated in bodily arousal also support emotional and attentional processes, including the ACC, insula, amygdala, and specific brainstem nuclei (Garfinkel et al., 2014). In these authors' study of the role of heartbeats in danger perception, fearful faces were detected more easily and were rated as more intense at systole (ventricular ejaculation phase), while being attenuated at diastole. Amygdala and neural responses to fearful faces were correspondingly greater at systole relative to diastole. Afferent physiological arousal signals represented within the amygdala were integrated with threat stimuli processing within each heartbeat, which enhanced psychological fear intensity. Thus, individual heartbeats improved fear perception and intensified the emotional impact of fearful faces (Garfinkel et al., 2014). IDs operated such that while low-state anxiety individuals inhibited relative fear perception at diastole, this was impaired in high-state anxiety individuals. Being characterized by enhanced cardiovascular activity, anxiety disorders (e.g., PTSD) are liable to result in high constant levels of perceived danger though neural networks signaling threat. The amygdala response in individuals with anxiety disorders can also be enhanced even in response to neutral faces (Garfinkel et al., 2014).

4.8 Neural correlates of fear, danger processing, and risk perception

Brain imaging studies have helped both to unravel and reveal something of the complexities of risk DM. Neuroscience research has the potential to contribute even more to our understanding of the nature of risk and the difficulties endured by individuals, groups, organizations, and societies faced with multiple risk issues. Features of risk DM that have accumulated through cognitive research are being widely investigated at the neural level, which inter alia aids understanding of how observable features of risk are represented at this substrate. Therefore, it is important to appreciate something of the extensive contribution that neuroscience is making to threat appraisal, risk perception, and R-T behavior. The years since 2006 in particular have witnessed a massive increase in research into neural correlates of risk DM, and R-T behavior, a sample of which is reviewed here.

SUMMARY TEXT 4.5 Role of Framing and Emotions in Decision Making

The framing effect (loss and gain frames as in prospect theory) and the affect heuristic were used by De Martino, Kumaran, Seymour, and Dolan (2006) to study the underlying neurobiology of how options are presented in rational DM. Using fMRI to explore the neural correlates of a financial DM task, the framing effect was associated with amygdala activity, suggesting a key role for emotions in mediating decision biases. That orbitofrontal cortex (OFC) and medial PFC activity predicted reduced susceptibility to the framing effect suggested that these regions could produce more rational choices by integrating emotional and cognitive information (De Martino et al., 2006). The study highlighted the importance of incorporating emotional processes within models of human choice, while also showing that the brain may modulate biasing effects to approximate rationality.

As predicted by the models, participants were risk averse in the gain frame—tending to select the sure option over the gamble option—and risk-seeking in the loss frame, preferring the gamble option. Decisions that ran counter to participants' natural risk-seeking/risk-averse tendency were associated with increased ACC activity and bilaterally in the dorsolateral prefrontal cortex (DLPFC) when the gamble option was chosen in the gain frame, and the sure option in the loss frame. ACC activation was consistent with the detection and mediation of conflict between predominantly analytical response tendencies, and a more emotional amygdala-based system (De Martino et al., 2006). Participants who acted more rationally showed greater activity in right OFC and VMPFC areas. Contrasting options were reflected in amygdala activity, which was significantly greater in the sure option in the gain frame. Greater amygdala activity was also associated with participants' tendency to be risk-averse in the gain frame and risk-seeking in the loss frame, indicating that the framing effect is driven by an affect heuristic underwritten by an emotional system. The authors suggested that the evolutionary basis for these effects might have been that incorporating a broad range of emotional information into DM could have conferred adaptive advantage to ancestral humans. However, in contemporary society, optimal DM requires manipulation of many more abstract and symbolic features as well as decontexualizing DM, so that the neural processes that once conferred adaptive advantage now often rendered choices seemingly irrational (De Martino et al., 2006).

In considering the respective roles of affect/emotion and cognition, Pessoa (2008) challenged functional anatomical models by reference to neural integration and high connectivity—as in network theory. Brain areas with high connectivity (hubs) are critical for linking regions, meaning that the distinction between affective and cognitive areas is not clear-cut as they interact and are integrated. For example, the amygdala is not only involved in processing fear and other emotional states, but also in attention and associative learning, which suggests that the amygdala is involved in emotional modulation of information. Evidence indicates that the amygdala is a highly connected hub that integrates cognitive and emotional information (Pessoa, 2008).

While the DLPFC may have a purely cognitive function, structures involved in emotion and cognition include the ACC, OFC, VMPFC, and inferior portions of the IFG, while the lateral PFC (LPFC) has an integrative function (e.g., memory for emotional content). While control regions for behavioral inhibition include the DLPFC, ACC, and inferior frontal cortex, because all stimuli have some value (costs, benefits, etc.) cognitive and emotional contributions to executive control cannot be separated. This means that the ventral tegmental area (modulatory effect from dopamine-rich neurons), amygdala, NA, OFC, ACC, and LPFC must also be included (Pessoa, 2008). Cortical regions associated with affect (e.g., OFC, ACC) are phylogenetically older. The hypothalamus is involved in volitional and reflexive behaviors, and is highly connected to many other regions. Parts of the basal forebrain are crucial for diverse attentional functioning, including selective, sustained, and divided attention and receive both cortical and amygdala inputs. Evaluating sensory information requires integration, and integrative connectivity hubs include the amygdala, hypothalamus, OFC/VMPFC, and ACC. The ACC is involved in computing benefits and costs of acting in general rather than just detecting conflict and error monitoring (see Chapter 5). The LPFC integrates affective and motivational information and so is also a control hub with many-to-many connectivity postulated (Pessoa, 2008).

Using repetitive transcranial magnetic stimulation (rTMS) to perform an inhibitory function in a gambling paradigm risk task enabled Knoch et al. (2006) to explore DM, laterality, and inhibitory control. The authors found that R-T was based on right hemisphere PFC activity so that participants made riskier decisions after disruption of right DLPFC (but not left DLPFC) function, revealing the right DLPFC to be crucial in suppressing enticing but risky options. The OFC was coactivated with the DLPFC, and adaptive risk DM depended on the extent of right hemisphere PFC activation. While risky choices took longer than safe choices, PFC stimulation could be modified, for example, by therapy or drugs (Knoch et al., 2006).

While early DM in a new task is exploratory due to ambiguity and learning, later DM is based more on known tolerances and thus is more risk-based. Using transcranial direct current stimulation (tDCS, facilitatory), with a BART methodology, Fecteau, Pascual-Leone et al. (2007) revealed that the DLPFC was involved in DM involving ambiguous choices. Participants receiving bilateral DLPFC, compared with either left or right DLPFC tDCS, developed a risk-aversive response strategic style. DLPFC activity was critical for adaptive DM, possibly by suppressing riskier options, while cross-talk between right and left DLPFC was identified as critical to effective DM (Fecteau, Pascual-Leone, et al., 2007). Risk-based DM involves known probabilities, with lower probability outcomes being worth more than higher probability outcomes. In DM involving ambiguity, probabilities are unknown and may/not equal rewards for alternatives. While the OFC was more involved in risky DM and inhibitory control, the DLPFC was more involved in ambiguous DM. In contrast with Knoch et al. (2006), Fecteau, Pascual-Leone, et al. (2007) found that the current task involved greater ambiguity and that the right DLPFC was important in the risk task, while DLPFC bilaterally was involved in the ambiguity task.

In another experimental task involving DM under risk conditions, Fecteau, Knoch, et al. (2007) again used tDCS neuro-modulation to explore the role of DLPFC in inhibitory control, and laterality effects. Simultaneous right anodal (to upregulate cortical activity)/left cathodal (to downregulate cortical activity) DLPFC (i.e., opposite directions) stimulation, resulted in a safer option being selected, faster option selection, and insensitivity to rewards, compared with opposite configuration and control (sham) conditions. These findings supported the notion that inter-hemispheric balance between right and left DLPFC is critical to risk-based DM. The authors explored the potential for therapeutic interventions to reduce dangerous R-T (e.g., addiction) behaviors (Fecteau, Knoch, et al., 2007). Adopting a signal detection theory framework, Falcone, Coffman, Clark, and Parasuraman (2012) used a tDCS methodology to explore perceptual performance and accelerated learning. In a complex threat detection task, it was found that participants trained using tDCS to the right inferior frontal cortex improved their skill acquisition and retention through enhanced perceptual sensitivity (coding of targets), which was maintained for 24 h (Falcone et al., 2012).

An applied neuro-ergonomics perspective was adopted by Parasuraman and Galster (2013) to determine means for improving performance in military and civilian environments. The sense-assess-augment (SAA) framework involves: (1) sensing/detecting an individual's/team's cognitive/functional state, (2) assessing that state relative to performance, and (3) augmenting performance to optimize mission effectiveness. The essence of Parasuraman and Galster's (2013) model is that human capacities are so rapidly falling short in the face of increasingly sophisticated systems, that by 2030 the authors' considered that there will be significant challenges to human capabilities in many systems and processes. This is likely to increase the probability of producing many error types (see Chapter 5), and require even more widespread adoption of sensory detection devices (see Chapter 3). Improved interfaces and augmented human performance will be increasingly required—for example, to address the joint problems of limited/depleted attentional resources and information overload to enable threat detection within degraded images or systems. To identify system bottlenecks, Parasuraman and Galster (2013) recommended using SAA. Threat detection requires inferring intent behind movement or action understanding and is enhanced by an attentional network that includes the superior temporal sulcus (STS), middle temporal gyrus (MTG), and the dorsal frontoparietal network, which modulates signals to action representation areas. Brain regions recruited for action understanding when confronted with a threat include the IFG, STS, MTG, intraparietal sulcus (IPS), and ventral premotor cortex. Augmenting human performance might be done by neuropharmaceuticals, noninvasive brain stimulation (e.g., tDCS, rTMS), or implants to improve attention, memory or alertness (Parasuraman & Galster, 2013).

Adolescents have been a particularly studied group in neuroscience-based studies of risk DM and R-T behavior. For example, Chein, Albert, O'Brien, Uckert, and Steinberg (2011) noted that peer presence increased the engagement of adolescents' reward circuitry to a greater extent than in adults, being associated with greater R-T in driving. The particular importance of social reward in adolescence prompted Rodrigo, Padrón, de Vega, and Ferstl (2014) to explore a range of effects in an adolescent sample, including ambiguous and risky DM, dangerous and safe choices, social context, age (late adolescents vs. young adults) and gender differences, and peer effects. Employing an fMRI methodology within a social context decision task, safe choices had high reward likelihood but low reward value, while dangerous choices had a larger value reward but a lower likelihood. Of particular interest was emotional and cognitive processing as well as developmental processes (Rodrigo et al., 2014).

Risky choices activated brain regions involved in aspects of social cognition such as theory of mind and self-reflection (bilateral temporo-parietal junction—TPJ, bilateral MTG, right medial prefrontal cortex—MPFC, and precuneus bilaterally). Also activated were cognitive control areas (right ACC—rACC, bilateral DLPFC, and bilateral OFC) but not reward centers (ventral striatum—VS). Making a dangerous selection also activated control areas (e.g., rACC) and emotional and social cognition areas (e.g., temporal pole). In risk situations, adolescents employed more right DLPFC and right TPJ resources than young adults did (Rodrigo et al., 2014). When selecting a dangerous option, young adults showed further engagement of ToM-related regions (e.g., bilateral MTG) and in motor control areas related to action planning (pre-supplementary motor area). The right insula and right superior temporal gyrus were more activated in women than in men, indicating females' greater emotional involvement and more intense modeling of another's perspective in the risky condition. In early adolescent development, socio-emotional incentive processing (System 1), located in VS, amygdala, OFC, and VMPFC regions, is used when evaluating and predicting rewards and punishments in DM. The gradually maturing cognitive control system (System 2), located in the DLPFC, parietal cortex, and ACC, operates in an executive function, including response inhibition and impulse regulation (Rodrigo et al., 2014).

Even though adolescent accessing of risk DM may be comparable with that of adults, the critical element for adolescent behavior is reward value (Luna, Padmanabhan, & Geier, 2014). While adolescents can assess risk as adequately as adults can, the problem is integrating this information with competing processes. The reward system is highly dependent upon dopamine neurons, which respond to reward prediction, expected reward value, salience, punishment, and valence. Dopamine receptors in the PFC and striatum/NA are more active in adolescence. As motivation plays a larger role in adolescent compared with adult behavior, there is a correspondingly greater demand on adolescents' inhibitory control circuits (e.g., OFC). Increased connectivity between VMPFC, striatum, fronto-parietal, and insular regions has been associated with reduced impulsivity (Luna et al., 2014).

The triadic model, the social information processing model (SIPM), and expected value, have been used as the basis for explaining why adolescents take more risks than either children or adults (Braams, van Leijenhorst, & Crone, 2014). These authors noted that cognitive immaturities could spring from neural, cognitive, emotional, and social factors. In adolescents, an imbalance between the development of subcortical regions (e.g., VS, amygdala) and the PFC meant that an emotion-driven approach to DM was particularly likely. While the VS is involved with reward processing and incentives-based DM, the amygdala processes highly salient motivational and emotional stimuli (e.g., potential threats, others' emotional states). PFC tasks include planning, response inhibition, and cognitive control.

The triadic model posits interplay between three systems: (1) approach system (VS) for rewards, (2) avoidance system (amygdala) to prevent harm, and (3) regulatory system (PFC). During adolescence, the balance tips toward the reward system. The SIPM proposes that social reorientation takes place during adolescence involving three brain regions corresponding to detection, affective, and cognitive-regulatory nodes. In the SIPM the affective node includes the VS and amygdala. The PFC is part of the cognitive-regulatory node, while the detection node comprises the fusiform face area, STS, and anterior temporal cortex for basic processing of social stimuli (Braams et al., 2014). Developmental R-T is ascribed to hormonally induced changes in the affective node, which elevate VS/NA activation in response to reward. Peer presence also enhances affective node activation. The social brain network, which includes the MPFC, precuneus, TPJ, and insula, is also developing during adolescence (Braams et al., 2014).

The widely accepted System 1/System 2 distinction characterizes System 1 as impulsive, associative, holistic, automatic, relatively undemanding of cognitive capacity, fast, acquired by biology, exposure, and personal experience, and highly contextualized task control. System 2 is identified as rule-based, analytical, controlled, demands cognitive capacity, slow, acquired by culture and formal tuition, and decontextualized. Beyond dual DM systems, triple systems are being proposed. For example, Wood and Bechara (2014) identified a third neural system that translates homeostatic bodily signals into feelings of craving, which modifies the traditional dual system. Wood and Bechara (2014) argued that the insula is critical in modulating the Sytem1/System 2 dynamics by translating bottom-up interoceptive signals into subjective experience of urges or cravings. This potentiates the System 1 activity and weakens cognitive resources required for the System 2 operation. The insula also governs the process required to correct homeostatic imbalance. System 1's neural basis is motivated reward/fear evaluative circuitry of amygdala-striatum (comprising NA, caudate, putamen, fundus, and olfactory tubule), which responds to dopamine (neurotransmitter) changes and primary inducers (in the world), and where controlled behaviors can become habits (Wood & Bechara, 2014).

Secondary inducers (thoughts, memories, reflections, etc.) induce emotional states via the VMPFC (which can modify evaluations), which links the amygdala-striatum system with DLPFC (working memory—WM function). The insula translates bodily states into conscious feelings ("System 3"). Both DM systems depend on brain regions involved in emotional processing (amygdala-striatum and VMPFC). Wood and Bechara (2014) noted that AI-generated feelings may alter motivational reward states (e.g., craving food when hungry). The likely role of the VMPFC in optimizing conservative options under risk and the function of the insular cortex in signaling the likelihood of aversive outcomes was indicated by Clark et al. (2008).

To aid survival, the AI warns the organism of potential internal threats. Emotional responses generated within subcortical structures, particularly the amygdala, are involved in initiating agonistic (defense/attack) behaviors (Stephan et al., 2003). In the brainstem, the periaqueductal gray (PAG) coordinates visceral and behavioral responses, particularly to inescapable stress or threatening stimuli. For example, the aversive interoceptive sensation of extreme visceral distention signals potential danger (Stephan et al., 2003). By integrating modality-specific information from multiple feeling states and contextually uncertain information with individual risk preferences, the AI is involved in uncertainty processing, including risk, risk prediction error, and uncertainty in DM (Bernhardt & Singer, 2012). Ventromedial frontal cortex lesions give rise to greater recklessness in decision making, impaired impulse control, and heightened social insensitivity (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Bechara, Damasio, Tranel, & Damasio, 1997; Churchland, 2002).

Considering IDs in DM uncertainty and ambiguity in daily life choices, including trade-offs and addiction, Platt and Huettel (2008) found that DMPFC activation was negatively associated with reward probability. As uncertainty increased, so did activation in the insula, LPFC, and parietal cortex—regions involved in behavioral control and executive function. While the VS was activated by the prospect of reward, gains, and losses activated the striatum, midbrain, ventral prefrontal cortex (VPFC), and ACC, such that activation increased with potential gain and decreased with potential loss, but with greater sensitivity to losses than to gains (Platt & Huettel, 2008). Ambiguity activated the lateral OFC, LPFC, and amygdala. Risk activated the parietal cortex, striatum, and precuneus. Risky DM involved the posterior cingulate cortex (PCC), which was also activated when rewards were uncertain, indicating an evaluative role in guiding behavior (Platt & Huettel, 2008).

A neuroeconomics DM framework provided Symmonds, Moran, Wright, Bossaerts, and Barnes (2013) with the basis for considering the role of the cortex in uncertainty, outcome asymmetry, and risk trade-offs, in lottery gambling. Risky choices were evaluated within 1–3 seconds, and the specialized brain circuitry underlying RP suggested a risk-processing network. Risk's independent dimensions (outcome uncertainty, outcome asymmetry) were encoded in distinct brain regions. The PPC accumulates perceptual evidence under uncertainty prior to action selection, the DMPFC is involved in encoding probability of loss and risk processing, while the insula is involved in risk processing, integrating subjective with objective risk preferences, and risk anticipation (Symmonds et al., 2013).

In Symmonds et al.'s (2013) study, risk encoding involved modulations in the left PPC (initiated 0–250 ms, peak at 250–500 ms) and right DMPFC (peak at 250–750 ms). Activity in the right somatosensory cortex (central sulcus) following risk encoding (750–1000 ms) predicted subsequent choices. Early and late effects in AI indicated subject-specific risk preferences, suggestive of a role for the AI in both risk assessment and risk anticipation during choice (Symmonds et al., 2013). IDs were represented as variance in AI and IFG activity prior to DM (in both 0–250 ms and 500–1000 ms time windows. Individuals tolerant of uncertainty and driven by the power of large (gambling) rewards showed an early (0–250 ms) increase in AI activity prior to selecting a gamble choice, while individuals with an opposite preference showed later (750–1000 ms) AI activity. AI activity thereby reflected an individual's risk preferences by predicting gamble and sure choices. Late AI activity was consistent with an anticipatory response prior to gamble choices for individuals with risk-averse preferences, while there was concurrent activation in the parietal cortex and PFC (Symmonds et al., 2013).

Reviewing strategies for delaying gratification (ignore, distract, reconstrue), Zayas, Mischel, and Pandey (2014) observed that delay of gratification may perform a protective function for individuals who have chronic personal vulnerabilities (e.g., dispositional rejection sensitivity) that increase their likelihood of experiencing aversive negative states. Neural correlates of gratification delay include the rACC, which is an emotional control area. System 1 (hot) components (primary reinforcers and punishers) include the amygdala, NA, and VS (processing appetitive stimuli). System 2 (cool) is based on the PFC regions, the IFG (maintaining information in WM, resolving conflicts between competing motor responses, inhibiting responses, and executing planned action), the LPFC (abstract rules representation), and the ACC (control monitoring). The key to delay of gratification is continuous interactions between hot and cool systems. The PFC and ACC are critical in reappraisal strategies. IDs in these networks accounted for differences in delay of gratification, which is remarkably stable over the lifespan (Zayas et al., 2014).

Observing the difficulty of drawing a line between healthy and unhealthy R-T, Reyna and Heutel (2014) noted that risk aversion was not the same as loss aversion. Exploring this domain, Reyna and Heutel (2014) noted that the AI processed many signals, including aversive emotions (e.g., anxiety, disgust) and cravings, homeostatic feelings, and abstract notions. Risk DM, particularly involving potential losses, is associated with AI activation. Insula-generated signals permit discrimination between uncertain stimuli and emotional salience messages from the amygdala, which give rise to subjective feelings about outcome uncertainty and valence (e.g., risk, loss aversion). The insula and amygdala thereby infuse options with emotional significance. The amygdala activates particularly to positive, negative, unusual, or interesting stimuli (Reyna & Heutel, 2014).

In selecting a reward, options are represented in the VMPFC/medial OFC, which responds to gains and losses, and computes a common currency signal to allow cross-domain reward comparisons (e.g., values, probabilities). These inputs travel to the ACC/DMPFC, which creates a set of rules to resolve DM conflicts (including error monitoring—see Chapter 5). ACC/DMPFC activation is greatest when DM requires choices that conflict with normal (e.g., habitual) responses (Reyna & Heutel, 2014). Often in conjunction with the ACC, the DLPFC serves as a cognitive control center, including response inhibition, cognitive distraction (distancing), and stimulus (re)appraisal. DLPFC activity is associated with successful self-control (e.g., selecting healthy over less healthy options) and lower R-T. When value signals translate into actions, PFC signals influence PPC activity that is consistent with a drift-accumulator choice process model (Reyna & Heutel, 2014). This model differentiates contributors to R-T behavior and identifies ways in which behavior change could mitigate potentially adverse (e.g., harmful) decisions. Current and anticipated rewards activate midbrain dopaminergic centers—the ventral tegmentum and substantia nigra, and the basal ganglia to which they project—the dorsal and ventral striatum (which includes the NA). Midbrain axons also project broadly to the PFC, particularly the VMPFC. This region's evaluation of rewards (represented as VS signals) and losses (costs represented as amygdala signals) accumulates in the parietal cortex (IPS) until a decision threshold is reached (Reyna & Heutel, 2014).

VMPFC and striatum activation varies with values in risky choice tasks. As the VMPFC is associated with the default mode network, this might suggest that activity here corresponds with different degrees of deactivation compared with the resting state. Distinct neural networks represent different reward types, for example, the dorsal hypothalamic region corresponded mainly to food reward, while the PCC responded mainly to monetary value (Reyna & Heutel, 2014). The VMPFC calculated trade-offs between different reward types. Dorsal ACC activation was associated with choice uncertainty or DM conflict. Choices leading to unknown outcomes (risk DM) were associated with right AI and bilateral caudate activation, while outcome uncertainty was associated with insula activation (Reyna & Heutel, 2014). As memory representations are generally encoded both directly (e.g., absolute amount of money to be won) and gist (essence—e.g., category or ordinal) formats, risk decisions are often based on gist representations rather than direct conversions. Greater use of gist-based strategies is associated with developmental processes from childhood to adulthood, and with better health outcomes (Reyna & Heutel, 2014). Adults are most likely to use gist-based processing in risk DM (Levin, McElroy, Gaeth, Hedgcock, & Denburg, 2014).

Avoiding negative consequences is important from an evolutionary perspective. Cognitive resource theory and framing effects provided the conceptual basis for Levin et al. (2014) to study the function of the circadian oscillator—the suprachiasmatic nucleus (SCN). Preference ratings were associated with corresponding brain region activations. Thus, uncertainty may generate a fear response from the amygdala, which processes fear responses and avoidance of negative outcomes. With the VMPFC being implicated in processing emotional stimuli, the fear response also activates the VMPFC, which mediates DM and allows for deliberative processing by linking WM and emotional systems (Levin et al., 2014). The insula impacts DM under uncertainty by providing complementary systems for dealing with potential loss in parallel with System 1/System 2 DM. Different neural systems are activated in the face of potential gains and losses—positive versus negative framing. Risky-choice framing effects were found to be stronger during circadian low points than during circadian high points, with more automatic processing occurring during circadian lows than during circadian highs, and deliberative processing more likely to occur during circadian highs. The SCN also regulates daily blood-glucose levels, with glucose-deficient individuals being less likely than glucose-enriched individuals to make optimal choices. Age-related decline was found in some DM areas but not in others (Levin et al., 2014).

The aging brain was the focus of Samanez-Larkin and Knutson's (2014) review of socio-emotional selectivity theory, which maintains that as time horizons shrink, humans are increasingly motivated toward optimizing well-being, so that everyday emotional experience becomes less negative. While striatum function is preserved in the aging brain, PFC-striatum connectivity declines, which may impair risky DM and learning about new rewards may also decline as a function of age. While fluid cognitive capacities (WM, attention, executive control) decline with age, crystallized cognitive function remains relatively intact (Samanez-Larkin & Knutson, 2014). Fluid cognitive decline is associated with changes in medial temporal and lateral PFC function, while affective function remains relatively intact. While actual monetary loss activity was like that of younger adults, when anticipating monetary loss, compared with younger adults, older adults showed reduced activity in the dorsal striatum and AI, and reported lower affect and arousal. This difference can be accounted for by older adults wishing to avoid negative thoughts/emotions, so that they attenuated anticipatory anxiety even though when losses occur they are just as keenly felt. Meta-analyses found no differences between older and younger adults' risky investment and gambling choices. Larger IDs are typically found in older adult samples, with many older adults showing no apparent decline. It is suggested that apparent age differences in risk preferences may actually relate to differences in (reward) learning ability (Samanez-Larkin & Knutson, 2014).

Lamme's (2010) 4-stage theory of consciousness involves two feedforward and two recurrent processing stages (see Summary Text 2.5). Recurrent processing involves increasingly widespread dynamic interactions between visual and fronto-parietal regions following stimulus onset. Also involved are brain areas mediating action, thereby producing a coordinated and planned response to visual information—in effect risk perception leading to behavior. Identifying the AI as the focus for the "neural self," Craig (2010) speculated that the AI might be organized in modules, including one for risk prediction.

Midbrain and dopaminergic regions and their targets, including the amygdala and VMPFC, have been identified as sites in which emotional aspects of DM are integrated with cognitive aspects such as utility evaluation (De Martino, Kumaran, Seymour, & Dolan, 2006; Heilman et al., 2010; Pessoa, 2008). Such cognitive–affect interactions may reflect the oft-reported phenomenon reported as the "dance of affect and reason" (Finucane, Peters, & Slovic, 2003; Slovic, Peters, Finucane, & Macgregor, 2005). The dual-process model (e.g., Hu, Wang, Pang, Xu, & Guo, 2015) is consistent with the neuroscience notion that emotion influences risk decision making, first, through the VMPFC as an internal motivator and second, via the ACC as a component of cognitive context (Tost & Mayer-Lindenberg, 2012). In this model, the ACC is influenced by higher-order cognitive processing areas, particularly the PFC, while providing top-down control of subcortical areas modulating stress response, salience, and negative emotion, particularly the amygdala and VS (Tost & Meyer-Lindenberg, 2012).

Neuroimaging experiments have generated knowledge about neural and endocrine mechanisms involved in behaviors associated with danger. For example, classical (Pavlovian) fear conditioning, a form of associative learning, involves a naturally occurring threat representing danger (unconditioned stimulus, UCS—e.g., angry or fearful faces) becoming associated with a previously neutral stimulus (conditioned stimulus, CS—e.g., a particular street). Fear-driven behavior may subsequently be activated along with associated endocrine responses when the CS alone is experienced (LeDoux, 2012).

Neural synaptic plasticity enables a learned association through UCS-CS convergence, which occurs in the dorsal subregion of the amygdala's lateral nucleus (LN). Direct connectivity allows information to flow to the amygdala's central nucleus (CN), which connects with hypothalamic (lateral hypothalamus and paraventricular nucleus) and brainstem (central gray) regions controlling autonomic behavioral and endocrine arousal (hormonal and neuromodulatory) responses to engage coping behavior (e.g., flight, freeze). Avoidance and related aversive behavior also involves learned UCS-CS associations in the LN, which in this case directs information through the basal amygdala. Connections to the VS, especially the NA and ventral pallidum, guide the UCS-CS association to the brain's motor regions, which direct aversively motivated behavior, such as escape (LeDoux, 2012).

While extinction training returns most LN activity to baseline, a subpopulation of ventral LN cells continues to respond to the CS, indicating that these cells contain an indelible memory trace that allows for rapid return of conditioned responses following extinction (Moscarello & LeDoux, 2013). Supplied with multimodal neurons that respond to auditory and somatosensory stimulation, the amygdala's LN projects to the basal nucleus and intercalated cell masses, which connect with the lateral and medial subnuclei, and the CN, which projects to the brainstem. Aversive conditioning appears to rely upon serial information processing, with the LN key to learning UCS-CS associations (Moscarello & LeDoux, 2013). The CN mediates CS-evoked exploration and risk assessment, which occur earlier, when a potential threat is relatively distal. The model thereby identifies the LN as learning and memorizing a UCS-CS association, while the CN evaluates threat-relevant information and determines behavioral responses to danger (Moscarello & LeDoux, 2013). Reflecting motivational asymmetry, Moscarello and LeDoux (2013) provided evidence that a qualitatively different parallel processing model involving amygdala structures applied to appetitive (approach) conditioning. A study of the role of the amygdala within the context of other brain regions in responding to threat is described in Summary Text 4.6.

Fear conditioning, a simple form of associative learning, is instructed by aversive stimulus-induced activation of pyramidal cells in the LN, a site of synaptic plasticity, to generate fear-based memories (Johansen et al., 2010a). Investigating neural pathways relaying UCS information to the LN and PAG during fear conditioning, Johansen, Tarpley, LeDoux, and Blair (2010b) revealed that expectation inhibited UCS-evoked responses in both regions. Johansen et al. (2010b) suggested that expectancy-modulated UCS information relayed by the PAG to the LN, as well as mediating the expression of fear responses, instructed associative plasticity essential for fear learning and memory formation. Evidence exists for PAG multifunctionality in various fear-conditioned responses, including freezing, analgesia, and vocalization, as well as reactions to aversive UCS experiences, such as shock (Johansen et al., 2010b).

Well-sited to accept sensory information in the form of danger signals, the PAG receives input from nociceptive (pain) and somatosensory neurons in the medullary and spinal dorsal horn. Nociceptive and neuromodulatory brain regions receiving PAG afferents projecting to the LN include the ACC, intralaminar thalamic nuclei, hypothalamus, LC, and ventral tegmental area (Johansen et al., 2010b). Reviewing fear memory components of acquisition, storage, and reconsolidation, and summarizing research on fear conditioning as a paradigm for characterizing learning and memory processes at a molecular level, Johansen, Cain, Ostroff, and LeDoux (2011) identified the potential for better understanding of the neural basis of such fear-related disorders as anxiety, PTSD, and

SUMMARY TEXT 4.6 The Brain's Response to Threats and the Role of Attentional Control

Information in this Summary Text is from the experimental study of Pichon et al. (2012).

Many situations (e.g., hazardous work, military operations) involve challenging tasks requiring disregarding potentially distracting information, including emotional signals. However, if danger arises (e.g., from either toxic release or enemy action) then the brain must be able to detect relevant salient stimuli rapidly, perhaps disengage from the current task, and allocate resources to defend against the threat. While high task demands reduce amygdala responding, the amygdala is particularly sensitive to threatening stimuli and operates relatively independently of whether a stimulus is attended to. For example, activity in the amygdala (and hypothalamus) increases in response to anger signals (in a potential aggressor). These two structures are part of a subcortical network that interfaces with motor and autonomic systems important in some emotions, including fear and rage. Thus, observing threatening actions (e.g., in a potential aggressor) also increases activity in regions involved in action preparation, including the PMC, pre-supplementary motor area (pre-SMA), and IFG.

Different brain networks respond depending upon the nature of a current task (e.g., whether it is involved in threat detection), whether attention is being deployed to a potential threat and whether emotional recognition is involved (e.g., observing emotions such as fear or aggression on others' faces). Those brain regions that responded to threats (e.g., aggressive expressions) formed a network that was independent of whether a current task was threat or nonthreat based, and comprised: amygdala PAG, left pre-SMA, left inferior frontal sulcus (IFS), bilateral AI, PMC, right thalamus, right dorsal hypothalamus, bilateral fusiform gyrus (FfG), bilateral STS, bilateral MTG, and left occipital pole. These regions are well-known for their role in emotional reactivity and are components of the defensive fear system in all mammals. For example, aggressive behavior results from stimulation of the medial dorsal hypothalamus.

Regions involved in responding to an attended threat were: left medial superior frontal gyrus (DMPFC), left posterior orbital gyrus, right IFG, bilateral anterior hippocampus/amygdala, right pulvinar, left thalamus, left parahippocampal gyrus, left TPJ/supramarginal gyrus (SMG), right FfG, and right STS. Brain regions showing an additive effect of threat during an emotional recognition task were: right lateral OFC, left dorsal IFG, right TPJ/SMG, bilateral FfG, bilateral posterior STS, right horizontal STS, right MTG, and inferior occipital gyrus.

It appears that two subcortical networks are important in task attention and threat detection. The first network, which is hierarchically organized, involves the amygdala, PMC, PAG, and hypothalamus, and is critical to fear-induced defensive reflexive action. Recruitment of these areas during attended, as well as nonattended threat, indicated that salient threat signals automatically trigger neural activity associated with reflexive defensive responding. Being impervious to attentional influence from task demands, these structures react to threatening stimuli irrespective of whether someone is attending to the emotional content of another's behavior and whether amygdala activity is task-modulated. Being independent of attentional control, associated motor control regions remain functional even when someone is engaged in an unrelated task. However, because all these regions respond to threat signals, they are likely to be critical for sustaining emotional processing independently of the amygdala. This network operates when the emotional content of a stimulus is sufficiently threatening to divert resources from a task and indicates that the amygdala can respond independently of selective attention. It is likely that by sustaining motor vigilance, this network evolved to cope with threat by supporting reflexive defensive behaviors.

The second network responds primarily when someone is attending to others' actions and their emotional content (e.g., fear, anger), and includes the amygdala and temporal cortical regions (e.g., FfG, STS), which can be influenced by both task demands and emotions. In both networks, emotions have evolved as efficient processing mechanisms that are highly adaptive to changing environmental demands.

It may be that to facilitate maximum responsiveness when required, the most effective form of danger perception system is a perpetual state of criticality. As flocking birds and shoaling fish maximize their survival likelihood against predators by enhancing detection capability through any individual spotting a predator and rapidly alerting the group, so interconnected neuron clusters operating close to critical transition could alert a person to possible danger. Criticality appears to mould neural connections into specialized modules, for example, a resting state network (Carhart-Harris et al., 2014). By extrapolation, it is possible that for an organization also being continually close to a state of critical preparedness is the most effective means of perceiving and addressing threats to its integrity. While not necessarily appropriate for all organizations, this would accord with models of effective operation of high reliability organizations (HROs, see Chapter 10).

---

phobias. While the CN participates in the acquisition of fear memory phase (Moscarello & LeDoux, 2013), by acting on the LN, sensory properties of an aversive UCS can have a powerful memory reconsolidation impact (Dębiec, Díaz-Mataix, Bush, Doyère, & LeDoux, 2010; Díaz-Mataix, Dębiec, LeDoux, & Doyère, 2011). Serial electron microscopy enabled Ostroff, Cain, Bedont, Monfils, and LeDoux (2010) to reveal that, being relatively robust, fear conditioning was associated with larger LN synapses, while safety conditioning was associated with smaller LN synapses. Development of optogenetic techniques to measure and control cellular function with millisecond precision promises to further enhance our understanding of learning and memory neural processes associated with fear conditioning (Johansen, Wolff, Lüthi, & LeDoux, 2012).

4.9 Developmental aspects

When deciding whether it is safe to cross a street, children must take account of both traffic speeds and their crossing ability. While adults typically make accurate size estimates of objects at 30–60 m distance, young children significantly underestimate objects' sizes at this distance (Granrud & Schmechel, 2006), with obvious implications, inter alia, for judging the speed of oncoming traffic as a pedestrian. However, because they can achieve size constancy (or even overestimate size) for distant objects by using cognitive strategies not available to younger children, 9-year-olds' size estimation abilities still exceeded those of 5 and 6 year olds at 60 m distance (Granrud & Schmechel, 2006). These authors found support for both the cognitive supplementation hypothesis (using cognitive strategies to judge the size of distant objects), and the perceptual learning hypothesis (using monocular cues such as linear perspective).

While infants' decisions to cross a potentially unsafe bridge depended on the probability of falling rather than the potential severity of a fall should it occur (Kretch & Adolph, 2013), the motivation to explore risky situations, while critical to skill development (Plumert, 1995), comes at a price. While adults only had difficulty making judgments about tasks just beyond their ability, 6- and 8-year-old children were also more likely to overestimate their ability to perform tasks that were well beyond their ability (Plumert, 1995). Overestimation of their ability was associated with accidental injuries for 6 year olds, but not for 8 year olds (Plumert, 1995). While experiencing success and failure in a task informs children about their capabilities, it does not inform the child about how much more or less they are capable of doing. In developing a skill, for example, one that could protect an individual from harm, DM requires weighing previous successes and failures and new challenges. Even with relevant prior experience, while at 6 years of age, children continued to overestimate their ability to perform tasks that were well beyond their ability at about 50% frequency, 8 year olds were able to benefit from prior relevant experience in making significantly more accurate judgments about their ability (Plumert, 1995).

Changes beyond infancy that inform skill development include increasing consistency of motor performance, and continuing experience of success and failure at tasks, thereby facilitating judgment. Motivational factors in skill development in children include degree of awareness of the aversiveness of error consequences and goal attractiveness, which may be particularly important influencers for younger children (Plumert, 1995). Skill development requires the motivation to achieve a goal even if the route to that goal involves overestimating one's abilities. The developmental dilemma is to continually aspire to trying new and difficult things, while not attempting those with highly adverse consequences. Children who find this distinction difficult are at higher risk of serious accidental injury (Plumert, 1995).

4.10 Perceiving dangers that cannot be sensed

Despite our evolutionary heritage providing us with multiple danger sensing mechanisms, a number of ubiquitous hazards, both natural and created, operate outside our direct sensing ability (Chapter 2). These include UV radiation—either from the sun's rays, or from human-created activity—and ionizing radiation, again either naturally occurring, but much more commonly from human-created nuclear operations. Detecting these hazards requires either equipment that supplants or augments human senses (e.g., Geiger counter) or else relies on appropriate transmission of scientific knowledge that bypasses the individual's sensing process by appealing directly to our perceptual processing. This might be through exposure to media dissemination of relevant knowledge about a hazard, motivation to search scientific literature about a hazard, or being alerted to a hazard by receiving advice from a respected authority (e.g., medical practitioner) for the threat to be acknowledged and acted upon. A range of conceptual models have been developed to represent this perceptual/cognitive process (e.g., extended parallel processing model, health action process approach, health belief model, protection motivation theory, and theory of planned behavior/theory of reasoned action).

An interesting example of a threat that cannot be directly sensed is anthropogenic climate change (WMO, 2013).* However, while the myriad components comprising this complex phenomenon may be beyond our immediate ability to sense, their outcomes, including increased frequency, variability, and intensity of weather or climactic events (floods, cyclones, bushfires, drought, etc.), may come to be perceived as threats that share a common origin. This realization may generate a search for information to either confirm or discount the perceived risk, which then becomes part of the individual's belief system. Once established as part of this belief system, it becomes less tractable, and whatever the scientific evidence may suggest, conflicting ideological positions may be the primary influence upon individual perceptions. Less controversial, but also claiming large numbers of lives annually, is air pollution (Raaschou-Nielsen et al., 2013; Silva et al., 2013).† Threats that are beyond our immediate sensing capabilities are more likely than those that we can sense directly to be subject to manipulation and influence from external parties.

Where the human sensory system is either incapable of identifying a disease or injury threat at an early stage, or else is insufficiently sensitive to, or aware of, symptom detection, then alternative systems are required for detection and threat management. These may be considered to be of two origins: (1) human cognitive processes, which are coterminous, or at least analogous with risk perception, and (2) community-based (e.g., health care system) processes, for example, involving various national or local interventions. These might include educational programs (e.g., self-examination), formal screening programs (e.g., stool testing, blood testing, breast examination, pap smears), or other detection systems, supported by medical or psychological interventions.

Jurisdiction-based programs can be combined with individual action to counter threats to personal health. Advocating a two-pronged approach, the WHO (2009) recommended: (1) targeting high-risk individuals who were most likely to benefit from large-scale interventions (e.g., vaccination) and (2) addressing risk across whole populations, regardless of the risks and benefits attributable to any individual. Population-based strategies are founded on the presumption that tackling large-scale risks by governments acknowledges the social and economic benefits of countering widespread diseases (WHO, 2009). More targeted strategies could adopt a segmented approach, whereby, for example, those already engaging in health-positive behaviors can be reinforced, those who are receptive to health-related messages and who are motivated to change can be provided with strategies to engage in changed behavior, while those who are either ignorant of health-related behaviors or unmotivated to engage in them can have their risk awareness increased with relevant information about personal harm generated by their current lifestyle. The WHO (2009, 2010, 2013) and other international bodies provide valuable global information about the major risk factors accounting for the vast majority of mortality worldwide, and top-down strategies for addressing this range of risks. Summary Text 4.7 outlines two governmental frameworks for such strategies.

* The WMO (2013) estimated that more than 370,000 people were killed by extreme weather events in the decade 2001–2010, a 20% increase from the previous decade.

† Silva et al. (2013) reported that more than 2 million people worldwide die annually (e.g., from lung cancer and respiratory diseases) as a result of atmospheric pollution, most of which is anthropogenic. In a prospective 17-cohort, 9-country study Raaschou-Nielsen et al. (2013) found no airborne particulate pollution threshold below which a lung cancer risk did not exist.

SUMMARY TEXT 4.7 Reducing Health Risks through Exercise and Improved Lifestyle Behaviors

Evidence for the beneficial effects of exercise for all age groups has been accumulating over many decades. As well as extending longevity, exercise has been associated with reduced likelihood of heart disease, stroke, type 2 diabetes, obesity, metabolic syndrome, fractures and other injuries, osteoporosis, depression, and some forms of cancer, as well as diminishing the likelihood, delaying the onset, and reducing the severity of dementia (DHHS, 2008). Evidence that cognitive performance in general, and attention, memory function, and processing speed in particular, are enhanced through exercise regimes, has been extended and further exemplified since the 1960s. It has been suggested that our ancestors' athleticism, for example, requiring sophisticated navigation during long-distance hunting trips, could have been critical in accelerating our contemporary brain power.

Official guidelines on recommended exercise levels have changed over time. While even relatively modest exercise (e.g., walking), if carried out sufficiently frequently, can generate measurable beneficial effects, short bursts of high-intensity training for those with adequate fitness levels, have been argued as providing substantial general health benefits. For example, the 2008 U.S. Physical Activity Guidelines for Americans recommended at least 150 min of weekly moderate-intensity exercise to maintain general fitness, with an emphasis on regular aerobic and resistance regimes beyond baseline levels for periods of at least 10-min duration (DHHS, 2008). However, a random sample from the U.S. National Health and Nutrition Examination Survey revealed that even short bouts (<10 min) of exercise could trigger benefits, and that as long as the total amounted to 150 min of moderate-intensity exercise per week, this was sufficient to maintain generally good health, for example, as measured by weight and BMI (Fan et al., 2013).

Explanations for potential pathways that might carry the cognitive enhancement effect of exercise include elevated mood, lower stress levels, reduced blood pressure, increased blood flow, and easier release of neurotransmitters such as serotonin, norepinephrine (noradrenaline), and dopamine, as well as growth-promoting hormones including growth factor-1 and brain-derived neurotrophic factor that promote new connections between cells. It is likely that these interconnected factors all have a role to play. Animal generational studies have found causal relationships between exercise and baseline levels of growth factors, and larger hippocampal and midbrain regions.

Drawing on the extensive behavior change literature and a seminal text (Thaler & Sunstein, 2008), the UK Behavioural Insights Team ("Nudge Unit") have produced a number of papers outlining ways in which social science knowledge of behavior influencers can be used to encourage behavior change to improve population health outcomes. The guiding principles have been distilled into a *MINDSPACE* acronym:

- *M*essenger: People are influenced by who communicates
- *I*ncentives: Individuals' responses are driven by predictable heuristics such as loss avoidance

- *N*orms: We are strongly influenced by what others do
- *D*efaults: People respond well to preset options
- *S*alience: Our attention is drawn to novel and relevant stimuli
- *P*riming: People's behavior is often influenced by subconscious cues
- *A*ffect: Emotions powerfully influence actions
- *C*ommitment: We seek consistency with our public promises and reciprocate acts
- *E*go: Our actions are designed to enhance our self-esteem

Lifestyle behaviors that will be targeted by the UK government's Behavioural Insights Team include smoking, unhealthy diet, excess alcohol consumption, and inactivity/lack of exercise. Importantly, behavior-change campaigns will be evaluated (Cabinet Office, 2010).

While acknowledging potential benefits of "nudge politics," using relevant examples Raihani (2013) observed that the efficacy of interventions could vary across contexts, so that targeted nudges were generally most effective in producing behavior change. Because some nudges could produce negative spillover effects, risking bringing about an opposite outcome to that intended, interventions requiring a single decision (e.g., organ donation, loft insulation) were most likely to be consistent with intended policy. Long-term effects of nudge policies have yet to be evaluated, and when policies are designed to maximize collective rather than individual benefits, ethical issues may need to be addressed (Raihani, 2013).

4.11 *Difficult to identify risks*

4.11.1 *Sedentary behavior*

Some hazards that lead to long-term harm may be difficult for us to identify as risks. The protective functions of sedentary activity that helped our ancestors to survive and recover from injury and infection now only apply when we are hospitalized or convalescing. As well as maximizing proprioceptive feedback to enhance lower limb strength and flexibility and to minimize injury likelihood, extended periods of long-distance barefoot running in our ancestral past was almost certainly critical for promoting continuing human survival and health, while from an evolutionary perspective, sedentary behavior is pathological and abnormal (Lieberman, 2012). In contemporary Western societies, sedentary behavior may be associated, inter alia, with technological advances in workplace systems (e.g., highly digitized control room functions, extended periods spent in front of computer screens), longer commuting distances (involving sitting in vehicles for lengthy periods), changing patterns of leisure activity (e.g., greater television and computer usage), and social behavior patterns (e.g., increasing contact via social media rather than face-to-face interactions). Insulin concentration is associated with time spent watching television, and with time spent using a computer (Ford et al., 2010).

Particularly when associated with increased caloric intake, sedentary behavior (multiple extended periods of inactivity), as distinct from insufficient exercise, is associated with increased likelihood of several forms of cancer and comorbid conditions such as type 2 diabetes, obesity, cardiovascular disease (CVD), and depression (Dunstan, Howard, Healy, & Owen, 2012a, 2012b; Lynch, Dunstan, Vallance, & Owen, 2013; Patel et al., 2010). Even a single day of sitting can reduce insulin action (Stephens, Granados, Zderic, Hamilton, & Braun, 2011). In a large prospective U.S. study, irrespective of physical activity level, time spent sitting was most strongly associated with CVD mortality risk for both sexes, and increased cancer mortality among women, as well as being independently associated with total mortality (Patel et al., 2010). These findings are consistent with those from studies in other Western nations, including Australia, Canada, and Japan (Patel et al., 2010).

Transmission mechanisms of reduced energy expenditure to ill-health include metabolic dysfunction involving increased adiposity (e.g., BMI > 25), suppressed enzyme activity, decreased skeletal muscle mass from reduced lipid metabolism, chronic inflammation, oxidative stress, postprandial hyperglycemia, and insulin resistance (Dunstan et al., 2012b; Lynch et al., 2013; Patel et al., 2010). Biomarkers for obesity, CVD, and other chronic diseases, include triglyceride levels, high density lipoprotein cholesterol, fasting plasma glucose, resting blood pressure, vistafatin concentration, and leptin (Patel et al., 2010; Rudwill et al., 2013). The simple antidote that enhances survival and quality of life, as well as promoting post-treatment recovery, is moderate to vigorous regular physical exercise for 75–150 minutes/week in addition to daily light-intensity activities (Lynch et al., 2013). Interrupting sitting time with short bouts of light- or moderate-intensity walking lowers postprandial glucose and insulin levels in obese and overweight adults (Dunstan et al., 2012b). Insulin concentration has been inversely associated with leisure time physical activity (Ford et al., 2010), while physical activity has been inversely associated with death rates from diabetes, as well as diseases of the respiratory system, the CNS, and the digestive system (Patel et al., 2010). Physical activity interventions that decrease cancer survivors' percentage of sedentary behaviors are likely to be particularly cost-effective in terms of health benefits (Lynch et al., 2013). There is almost no human ailment that might not be reduced in intensity or likelihood of occurrence by regular exercise.

4.11.2 Generic health threats

While immediate threats to safety may be obvious, the role of socio-cultural and economic factors in relative ill-health risk may only become apparent in the light of extensive research evidence. For example, in comparing the health risk to U.S. residents with those of residents of 16 other economically advanced nations, Woolf and Aron (2013) identified a "consistent and pervasive pattern of higher mortality and inferior health in the United States, beginning at birth" (p. 2). The comparative risks are particularly great for U.S. residents under 50 years of age. Despite its per capita level of health spending far exceeding that of any other country, compared with peer country averages, the U.S. fared worse in: adverse birth outcomes, injuries (e.g., from traffic crashes) and homicides, adolescent pregnancy and sexually transmitted diseases, HIV and AIDS, drug-related (including alcohol) mortality, obesity and diabetes, heart disease, chronic lung disease, and disability. While the health disadvantage is particularly prevalent among economically disadvantaged sections of the U.S. population, upper-income groups were also in poorer health than their counterparts in comparison countries (Woolf & Aron, 2013).

Multiple structural reasons identified as contributing to the comparatively poor showing of U.S. population health included: a highly fragmented health care system, limited public health and primary health care resources, a large proportion of the population being uninsured for health, lower access to "safety net" provisions, high poverty rate, high income inequality, and declining educational attainment. Behavioral factors included: high per capita caloric consumption, abuse of prescription and illicit drugs, reluctance to fasten seatbelts and to wear safety helmets, more traffic crashes involving alcohol, earlier and more frequent sexual partners, reduced likelihood of practicing safe sex, and firearm ownership/use. Combination factors included built environments designed for vehicle travel that discouraged physical activity, food consumption patterns shaped by powerful industrial, agricultural, and retail organizations, ready availability of legally sanctioned firearms, limited transport options generating over-reliance on private automobile use, poor enforcement of drink-driving legislation, and poor vehicle and highway maintenance (Woolf & Aron, 2013). Addressing these issues requires a combination of efforts to change both political governance and individuals' behaviors, including enhancing their perception of the health risks.

4.12 *Role of consciousness and cognition*

Rather than artificially distinguishing between consciousness, attention, and various types of memory, Bor (2012) argued that a more parsimonious way of characterizing cognitions was between processes that, on the one hand, were static, automatic, and unconscious, and on the other were dynamic, flexible, and conscious. Sergent and Dehaene (2004) identified parietal, cingulate, and frontal cortices as being involved in conscious perception, regardless of the triggering sensory stimuli. Bor identified automatic processes, including overlearned habits and goals, as the product of our "roaming consciousness," being stored in the brain's specialized motor areas. When a task cannot be completed by the habit bank, consciousness operates by seeking more information and using working memory to solve novel or complex tasks. This neural process, which reflects Rasmussen's (1983) distinction between skill-based (habits) and knowledge-based (requiring conscious attention and memory) behaviors, could then generate new automatic responses (Bor, 2012). The search for new information (e.g., hazards in a novel environment) will particularly excite the prefrontal parietal network.

In a risk DM experiment, in support of affective generalization theory, and confirming other studies (Peng, Miao, &, Xiao, 2013; Shavit, Shahrabani, Benzion, & Rosenboim, 2013; Young, Goodie, Hall, & Wu, 2012), Hu et al. (2015) found that more than negative emotion (induced grief), positive emotion (induced pleasure) rendered participants R-T prone, as did high time pressure compared with low time pressure. Further, a significant interaction revealed that while high time pressure increased R-T when emotions were positive, it decreased risk-taking when emotions were negative—reported as an emotional polarizing effect. To account for their findings, the authors proposed a dual cognitive DM pathway model. A simpler, relatively superficial high-error rate faster route they called the *impulsive pathway*; and a more complex, deeper, more precise, slower route they called the *optimal pathway* (Hu et al., 2015). The impulsive pathway is used to evaluate a small number of simultaneous needs or motives, for example, when there is time pressure, while the optimal pathway is used under normal conditions. The parallels with Slovic's (2010) dual-process (cognitive and emotional) theory and Kahneman's (2011) notion of thinking fast and slow are peremptory.

Porges' (1998) notion of a social engagement system relates to his 3-stage evolutionary polyvagal theory that explored the brain's assessment of safety or nonsafety in relation to three phylogenetically dependent neural systems of affective regulation. In the first stage, associated with the dorsal vagal complex (DVC), response to threat is characterized by conservation of metabolic activity, which translates as immobilization behavior driven by fear and avoidance. In the second stage, the sympathetic nervous system (SNS) can increase metabolic output and inhibits the visceral vagus to foster mobilization behaviors that prepare the organism for "fight or flight" (FoF), which is costly in metabolic terms. In the third stage, involving the ventral vagal complex (VVC), and which is unique to mammals, the myelinated vagus can rapidly regulate cardiac output at minimal energy expense to engage or disengage with the environment, and is associated with safety and trust. Perceiving the environment as either safe or unsafe transmits neurally to the brainstem via corticobulbar pathways originating in the frontal cortex, and is associated with alertness. Cortical regulation of the VVC is maximized during cortical activation when the individual is alert and perceives the environment as safe. If a threat is perceived, the depressed VVC disengages the vagal brake to facilitate the SNS to mobilize for FoF (Porges, 1998). When the environment demands a calm behavioral state, for example, when faced with imminent danger, engaging the VVC vagal brake reduces heart rate and induces calming behaviors (Porges, 1998).

In Porges (1998) system, for determining the safety or nonsafety of the environment, the cortex and amygdala influence communication in the hypothalamic-DVC. If danger is perceived then central vasopressinergic pathways activate adaptive mobilization as the hypothalamus communicates with DVC components to change the vagal reflex set-point. Immobilized fear, generated by vagal motor nuclei surges to the viscera, occurs when FoF behaviors are not an option. When an individual perceives conditions to be safe, a trust response is generated by central and system oxytocin release. Individuals under threat tend to highlight differences between those who are similar and dissimilar to themselves (Siegel, 2009).

4.13 Risk and decision making

Describing two rare cases of early-onset (<16 months) degraded decision making, Anderson, Bechara, Damasio, Tranel, and Damasio (1999) found that PFC damage impaired social behavior so that it resembled psychopathy, including absence of moral reasoning, emotional neutrality, antisocial behavior, and insensitivity to future consequences of decisions. Brain areas affected included either bilateral or right VMPFC. Late-onset damage in comparable areas did not correspond with the same behavioral syndrome as individuals would have been able to acquire socially relevant knowledge (Anderson et al., 1999). Experimental studies at around the same time, particularly using IGT methodology to simulate DM uncertainty, rewards, and penalties, found that DM was preceded by a nonconscious biasing step using (intuitive) systems other than those supported by declarative knowledge, as revealed via anticipatory skin conductance responses (Bechara et al., 1997). VMPFC damage disrupted this somatic marking and also the intuitive processing system. It was indicated that parallel (and perhaps interacting) processes were operating—one reasoning and the other intuitive. The authors surmised that the VMPFC holds dispositional knowledge, which activates autonomic and neurotransmitter nuclei to deliver dopamine to selected reward-sensitive regions (Bechara, Damasio, Tranel, & Damasio, 1997).

Later experimental work included the social context for risk DM, for example, postulating risk-sensitivity theory and dominance theory (hypothesizing the emergence of a stable ranking within a group) as a means of regulating risk motivations (e.g., competition for resources) within a group (Ermer, Cosmides, & Tooby, 2008). It was revealed that males' DM was affected by whether others were watching and their status relative to the one observed. Men who thought that others of equal status were evaluating their decisions were more likely to favor a high-risk/high-gain means of recouping a monetary loss over a no-risk/low-gain means with equal expected value. Dominance theory suggested that male cognitive processes generating risky DM are driven by the motivation to negotiate a status-saturated social world, such that individuals have a status index generator for determining their status relative to another (potential competitor). A cue-activated regulatory function serves to generate levels of R-T that would have been adaptive in ancestral situations when competing for resources and when fitness promotion determined optimum payoffs. For any two individuals who perceive themselves to be of equal rank, motivation to take risks in pursuit of resources are up-regulated, while observers gain insights regarding their own status. R-T is lower when individuals of unequal rank compete, resulting in a U-shaped R-T function in response to relative status (Ermer et al., 2008).

IGT methodology combined with the somatic marker hypothesis has been a frequently used framework in risk DM studies. The basic tenet is that cognitive activity (e.g., DM) is guided by central feedback of bodily arousal responses, marked by an emotional alarm signal (Werner et al., 2013). Werner et al. used fMRI and a heartbeat perception paradigm to explore neural responses to perceived somatic feedback (interoceptive awareness). Interoceptive awareness and accurate DM were associated with neural activity in the right AI (rAI) and left post-central gyrus, which contains the primary somatosensory cortex, supporting the role of somatic feedback in DM, as represented in the rAI. Bodily states are known to be important in DM, and somatic markers represent and regulate the brain's emotional circuitry, including the MPFC, amygdala, insula, somatosensory cortex, and certain brainstem nuclei (Werner et al., 2013). Activation of this circuitry helps rapid DM by directing attention toward negative outcomes and acts as a danger warning signal. VMPFC lesions have been associated with impaired somatic signal processing and DM, as well as impaired skin conductance responses. Individuals who display more accurate sensitivity to bodily signals (e.g., heartbeat awareness) have better CNS function and show superior DM (Werner et al., 2013).

Dual-process theory and future orientation (FOT, as measured by Zimbardo's Time Perspective Inventory) provided the framework for Eskritt, Doucette, and Robitaille's (2014) IGT experiment. IGT performance was related to emotion regulation, while FOT was associated with reflective (System 2) DM but not necessarily to intuitive (System 1) DM (Eskritt et al., 2014). FOT initiates at age 3–5 years and continues to develop into adolescence. Taking a more present time perspective was associated with R-T (e.g., in driving). Engaging in mental time travel is a central feature of System 2 DM. However, the authors emphasized that seeking to make adolescents aware of future consequences of their actions will not necessarily reduce R-T behavior, particularly when this is based on System 1 processing (Eskritt et al., 2014). From their IGT-based survey of pathological video gaming, impulsivity, and reward processing, Bailey, West, and Kuffel (2013) reported that around 7% of an all-male sample of college-aged adults met criteria for pathological video gaming. While hours spent on first-person shooter gaming was positively associated with impulsivity and R-T, hours spent on strategy games was negatively associated with impulsivity. Certain video games (e.g., car racing) appear to prime risky DM and R-T. Gaming and pathology were positively associated with reduced sensitivity to negative outcomes (e.g., hours spent gaming/week) and pathological symptoms predicted greater R-T that was resistant to learning to avoid higher risk preferences. However, strategy gamers were more sensitive to negative feedback as mistakes made in a strategy game can be costly in the long term (Bailey et al., 2013).

The framing effect postulates that as DM moves from risk seeking to risk avoidance, the sure option tends to be selected. Using fuzzy trace theory (FTT) in their study of risky choices employing gain and loss frames, Reyna, Chick, Corbin, and Hsia (2013) found that decision makers coded both verbatim and gist representations. However, in a developmental reversal effect, adults performed worse than either children or adolescents. In this study, intelligence agents showed larger decision biases than college students did, revealing larger framing biases and also greater confidence in their DM. While framing biases appear irrational (equivalent outcomes are treated differently), they are the output of cognitively advanced mechanisms to construct meaning (e.g., developing experience-based or gist-formulated intuition at the expense of a literal/verbatim approach). Thus, framing biases (and other biases and heuristics) develop with age. When outcomes were framed as losses rather than gains, agents were more willing to risk human life. The authors maintained that FTT was superior to both prospect theory (PT) and EUT at explaining their results (Reyna et al., 2013).

As a type of dual-process theory, FTT maintains that people think about risk in at least two different ways: (1) qualitative gist-based (e.g., "avoid risk"), and (2) quantitative, involving risk–benefit trade-offs. An experiment to account for apparently contradictory findings with respect to adolescent R-T was described by Mills, Reyna, and Estrada (2008). The authors discovered that RP reflected the extent to which adolescents engaged in risk behavior, with measures emphasizing verbatim retrieval and quantitative processing showing positive associations between RP and risky behavior. However, measures assessing global gist-based risk judgments were negatively associated with R-T, indicating a protective relationship. Results supported a dual-processing relationship between RP and R-T such that the relationship depended on whether cues triggered verbatim or gist processing (Mills et al., 2008). Increased R-T was associated with risk–benefit trade-offs because this often favored R-T for the relatively low risk of engaging in a single risky act (rather than engaging in many such acts over time). Global (gist-based) judgments ignored or downplayed the benefits side and, therefore, were much more likely to be protective. Individuals who conceived of risk in gist terms were more likely to perceive the risk of engaging in an activity as high, and engaged in less R-T. RPs can be either protective or reflective of R-T depending on an individual's R-T history and retrieval cues adopted in response to questions. Thus, retrieval cues primed by questions could produce either positive or negative associations between RP and R-T within the same individual. While risk-takers denied vulnerability when risks were assessed on global gist perceptions, they acknowledged it when cued to retrieve specific behaviors (Mills et al., 2008).

An experimental dual-process theory framework was the basis of Białek and Sawicki's (2014) study of debiasing, deferred gratification, and taking an expert's perspective. Taking the perspective of an (imagined) expert led participants to become more risk averse, less impulsive, and more likely to inhibit their preferences, which forced the individual to override their intuitions and conform with what they perceived to be a social norm for expertise. It was concluded that asking people to use System 2 (rational) DM rather than System 1 (intuitive) processing can debias some behaviors, for example, making financial investments (Białek & Sawicki, 2014).

4.14 Risk preferences

A number of studies have used the experimental paradigm to explore risk preferences. To study the effect of induced mood on R-T, Yuen and Lee (2003) found that depressed mood was associated with reduced R-T tendency as the world is then seen as more threatening. The asymmetric effect was that negative mood had a larger effect than positive mood did. Prospect theory takes account of the subjective value of a change in circumstances and the assessed probability of potential outcomes. Using this probability framework to explore choice, in a gambling DM task, Young et al. (2012) found that time pressure could lead to increased risk attractiveness or risk-seeking behavior. Generally, time pressure produces worse decisions and lower confidence by decision makers in their decisions. Under time pressure, because risk preferences depend on expected outcomes, people may be attracted to risks with positive expected outcomes, but become averse to risks with negative expected outcomes. Time pressure made people more risk seeking in the gain domain, but impeded probability discriminability in the loss domain (Young et al., 2012).

While emotions are often held to be brief and specific, moods are considered to be relatively long lasting and general. The affect infusion model (AIM) maintains that positive mood increases R-T, while negative mood reduces it. The MMH posits that people in a positive mood tend to be more risk averse so as not to disturb their mood. A lottery task allowed Drichoutis and Nayga (2013) to study risk aversion, mood, affect, and time preferences. While positive and negative moods increased both patience and risk aversion, the effects were differential. The authors proposed that an integrative model, combining AIM and MMH, could account for the interaction effect that risk preferences were affected by whether a cognitively demanding task preceded a risk preference elicitation task, but only when the person performing it was in a negative mood (Drichoutis & Nayga, 2013).

Prospect theory identifies the loss function as normally being steeper than the gain function, as a result of memory effects. To determine whether the so-called house money effect (sunk gains) could account for an absence (or reduction) of loss aversion, Peng et al. (2013) introduced 2-stage gambles to determine whether these were assigned to different mental accounts (e.g., a windfall account or "easy come, easy go" for sunk gains). It was revealed that prior gains increased people's willingness to accept risky gambles. This is because the potential loss from prior winnings has a low psychological value so that participants were more risk seeking (the pain of losing a $100 allowance is far worse than losing $100 of gambling winnings). The quasi-hedonic editing effect meant that money from gambling winnings was spent more easily than was money earned from work (Peng et al., 2013).

The IGT methodology was combined with the somatic marker hypothesis by Singh (2013) to explore the emotion-cognition dual conception of risk. The author sought to determine the effect of delayed versus immediate reward, reward frequency, and System 1/System 2 effects. Sleep deprivation and a short test-retest gap attenuated the difference between cognitive and emotional risk preferences, while DM benefitted from repeated task exposure. The author surmised that inconsistent R-T over time could be due to factors affecting the dichotomized emotion-cognition features of a task (Singh, 2013).

4.15 Cognitive (attributional) biases

Cognitive, or attributional, biases have been well-established in the research literature and can have considerable implications for the accuracy of risk perceptions. Self-assessments that are subject to these biases tend to be flawed in particular ways so that they are more or less universal. For example, overconfidence is revealed in numerous ways, while the planning fallacy leads us to underestimate the time that it will take to complete various tasks (Dunning, 2006). Individuals tend to regard themselves as more disciplined, idealistic, socially skilled, a better driver, good at leadership, and healthier than the "average person" (Dunning, 2006). Some of these biases may be beneficial in certain circumstances, for example, it may benefit an individual with cancer to overestimate the likelihood that they will live beyond the time period specified by a medical practitioner (Taylor & Brown, 1988).

However, more commonly, overestimating likely performance can be very costly. For example, the 2008 global financial crisis was considered to have partly resulted from overconfidence among bankers and other financial "experts" in the robustness of the global financial system (Helleiner, 2011). In such cases, cognitive biases may be magnified by group-based effects. Other examples include the overconfidence of groups central to several celebrated human-technology interface disasters, including Chernobyl (Reason, 1988a) and the *Challenger* and *Columbia* accidents (Mahler, 2009).

An individual-level example is that while a large percentage of people confidently believe that they are reliably alert to high blood pressure episodes (which cannot be sensed), leading them to take medication only when attending to their perceived "symptoms", this false belief leads to incorrect medication (Meyer, Leventhal, & Gutmann, 1985). Health may be adversely affected by similar false beliefs—for example, teenage girls who rated their birth control knowledge most highly were also most likely to become pregnant (Jaccard, Dodge, & Guilamo-Ramos, 2005). Elderly drivers referred for evaluation who rated themselves as "above average" were four times more likely to be classified as "unsafe drivers" than were those who rated their driving ability more modestly (Freund, Colgrove, Burke, & McLeod, 2005). Thus, cognitive biases can be a serious impediment to accurate risk perception.

4.15.1 Reframing cognitive biases

The notion that cognitive biases influence DM originates in rational models, particularly those grounded in an economic approach to human behavior, such as EUT and PT. However, as these theories make no predictions, inter alia, for IDs or environmental effects (Ermer et al., 2008), an increasing body of literature suggests that such influences on DM are misconceived on the grounds that these attributed "biases" reflect a more broadly based conception of what motivates human behavior. Promoting risk-sensitivity theory, originally derived from animal ecology observations, as a unifying model that can accommodate the essential tenets of EUT and PT as well as heuristic approaches, Mishra (2014) advocated a motivational approach to DM based on EP. While IDs (e.g., impulsiveness, SS, neural deficits) can influence DM, the evolutionary framework operates to generate risk decisions through interactions between life history impacts (e.g., nature of parenting, social background, socialization), developmental stage (primarily age), current needs relative to the experienced environment (e.g., competition for wealth and social/marital status), and extant circumstances (e.g., un/employment, assets). Rather than cognitive rationality driving DM, ecological rationality to maximize fitness motivates DM for action.

What have been interpreted as age and gender effects on risk DM, from a risk sensitivity perspective reflect current circumstances within a framework in which DM has adaptive capacity. For example, in competing for resources, social status, and mates, young males' optimizing strategy might be to take risks in order to increase the likelihood that desired outcomes will occur. The downside is that harm could result. However, for young males, R-T or even apparently reckless behaviors might still represent ecologically rational DM options. As young males compete with older males as well as with each other in several domains (e.g., mate access, social status, employment opportunities), R-T might appear as dispositional. However, considering each domain separately, low-risk strategies may be unlikely to bring the desired outcomes, so that R-T in young males can be construed as individualized responses to different social circumstances (Mishra, 2014). Thus R-T is domain-specific. Initially, survival needs are paramount, after which reproduction and status needs motivate behavior. Much as in Maslow's hierarchy, only when needs have been satisfied do risk-averse strategies become optimal.

In risk-sensitivity theory, any disparity between an individual's current state and a goal state motivates behavior to address the shortfall. Crucially, if a low-risk strategy cannot bridge the gap and a high-risk option offers the possibility of doing so, then the ecological rationale prompts the individual to select a high-risk option. Thus, crime and other "deviant" behaviors (e.g., dangerous driving, drug use, gambling to excess, risky sexual practices) can be construed as ecologically rational if they occur in response to otherwise desperate circumstances (e.g., unemployment, extreme poverty, lack of a mate) as they have the potential to generate the wherewithal to bridge need gaps, despite the downside risk (Mishra, 2014). Perceived costs and benefits of risk options are risk sensitivity components, but have to be considered within the context of an individual's current needs gap and the environmental opportunities to address that gap. At any stage of a person's life history, trade-offs result from choices about devoting time, effort, and resources between options (securing a mate, obtaining satisfying employment, raising offspring, etc.). While there are typical effects in terms of age and gender behavior patterns, R-T propensity remains flexible throughout the lifespan, responding to the impact of changes in social and economic circumstances upon individuals' need states (Mishra, 2014).

What have been interpreted as cognitive biases can be explained using risk sensitivity theory. Within a risk sensitivity fitness framework, marginal losses may be very much worse than marginal gains, thereby accounting for PT's framing effect. Anchoring or focusing effects and the negativity bias can be construed in loss-aversion terms as some aspects of an issue being emphasized over others when a person considers their current needs within the context of environmental opportunities. The availability (salience) and representativeness heuristics can be understood within a risk sensitivity perspective as reflecting past experience that events cluster together (e.g., predator, for which read terrorism, attacks). Overestimating both rare and certain outcomes can be understood as reflecting DM that seeks to meet a need requiring either confirmation (certain gain if the need is low), or the possibility of a very large gain (e.g., lottery win to meet a high need), even if this is very remote (Mishra, 2014). A more detailed consideration of cognitive biases and how these might affect DM under uncertainty, particularly in situations involving risk, is in Summary Text 4.8.

The so-called affect bias or heuristic, might not be considered to be a bias at all, but should be more appropriately be characterized as integral to much DM, as evidenced by both theoretical (e.g., Loewenstein, Weber, Hsee, & Welch, 2001) and neuroscience (Pessoa, 2008) contributions to our understanding of DM processes. While many studies have shown affect to be a strong driver of responses to risks and DM, the affect heuristic—evaluating the goodness or badness of a risk (Kahneman, 2011; Slovic et al., 2005) appears to influence deliberative (explicit) rather than associative (implicit) processing of risk–benefit decisions (Townsend, Spence, & Knowles, 2014).

Risk sensitivity theory can also account for the emotional component of DM, for example, that negative emotional states have generally (but not always, exceptions include sadness and depression) been associated with greater R-T, while positive states have sometimes (but not always) been associated with risk aversion. Thus, while fear has typically been associated with risk aversion because of the need to escape to safety, anger (also frustration, resentment) has been linked with R-T due to vengeance seeking or other motivations. However, risk-sensitivity theory posits that emotions guide DM according to the strictures of biological fitness. Thus, anger, resentment, and disappointment might be driven by a need created by the disparity between a current state (e.g., being deprived of a desired outcome relative to others) and a goal state (Mishra, 2014). DM for risk developed over many millennia, during which time circumstances and human needs were quite different than in our contemporary world. Only by seeking to understand this historical legacy can we begin to appreciate the subtleties of contemporary risk DM.

SUMMARY TEXT 4.8 Evolutionary Account of Cognitive Biases*

While all cognitive biases incur some potential psychological costs because by definition they are false beliefs, from an evolutionary adaptive standpoint, the key issue is the extent of trade-offs between false positive (belief in something that is untrue) and false negative (not believing something that is true) beliefs (Johnson, Blumstein, Fowler, & Haselton, 2013). Cognitive biases have developed as a ubiquitous feature within the animal world to minimize these trade-off costs, thereby enhancing the fitness of individuals within a species, and therefore the entire species.

Arguing that much of the research on cognitive biases can be understood from an evolutionary perspective, Haselton, Nettle, and Andrews (2009) and Haselton and Galperin (2012) suggested that many cognitions, emotions, and behaviors, rather than being generated by irrational decision making, have been selected to address critical survival and reproduction problems. To appreciate this adaptive rationality under conditions of uncertainty† involves understanding the social context within which much behavior occurs, which requires naturalistic rather than controlled laboratory studies.

Prime among factors that could promote various forms of false beliefs are human needs for social protection, harmony, and mating success, which would predispose individuals to harbor beliefs (e.g., religious) that would maximize their group affiliation and potential mate attractiveness, rather than the veridicality of such beliefs. Truth is relevant to the extent that it contributes to survival and reproductive success (Haselton et al., 2009). Subject to sex differences, biased self-perception, for example, relating to past performance, could be adaptive from the perspective of improved future performance, thereby possibly enhancing social or mate attractiveness (Schaller, Park, & Kenrick, 2007). Judgments made on the basis of small samples may reflect humans' limited working memory capacity, which can be adaptive when rapid decisions (using heuristics) are required in the face of constrained information availability. The well-documented hindsight bias might result from an adaptive memory process that learns from feedback to shift toward a revised version of reality (Haselton et al., 2009). While their position has been challenged (e.g., Marshall, Trimmer, & Houston, 2013; Marshall, Trimmer, Houston, & McNamara, 2013), arguing that because it can maximize individual and collective fitness as long as benefits from contested resources are sufficiently large, Johnson and Fowler (2011) reasoned that despite its contribution to hubris, stock market crashes, policy failures, costly wars, and human-induced disasters, the overconfidence bias is consistent with evolutionary stable populations. Johnson and Fowler (2011) also noted the bias in how overconfidence is perceived, in that it may primarily be identified when it is associated with failure (e.g., industrial disasters, gross war casualties).

However, by boosting morale, ambition, resolve, and persistence in uncertain competitive environments, including bluffing, overconfidence can assist

* While they are distinct entities, in the current discussion, "cognitive biases" includes attributional (e.g., social), emotional (e.g., fear), and behavioral (e.g., outcome) biases. For an account of the distinction between cognitive and behavioral biases, see McKay and Efferson (2010).

† Rarely are decisions made except under uncertain conditions.

in generating benefits with sufficient frequency to have been reinforced over humans' evolutionary time span. Therefore, this generic bias could even persist when bluffs are called, as could happen eventually (Marshall, Trimmer, Houston, & McNamura, 2013). From modeling alternative strategies, Johnson and Fowler (2011, 2013) determined that overconfidence was advantageous in terms of encouraging individuals to claim resources they would not otherwise win, and kept them from avoiding contests they would anyway win. In contrast, competitive strategies based upon unbiased DM do not necessarily deliver optimum outcomes in terms of maximizing benefits over costs (Johnson & Fowler, 2011). Johnson and Fowler also pointed to the role of increasing uncertainty (e.g., climate change, new leaders, complex international relations) in generating extreme over (or under) confidence when strategic environments are least well understood.

Applying error management theory* (EMT) to biases for avoiding (potentially) dangerous people, Haselton and Galperin (2012) identified an evolutionary legacy of intergroup conflict as predisposing humans to suspect out-group members in the absence of strong contrary evidence. Noting that distinct racial differences between human groups arose as a result of migrations between 100,000 and 200,000 years ago, Olsson, Ebert, Banaji, and Phelps (2005) surmised that fear conditioning representing threat with respect to racial differences probably arose as a result of perceived dissimilarities between social groups. For ancestral humans to misperceive potential violence from unknown others could have been very costly, whereas assuming out-group members to be potentially violent would normally have incurred few costs (the case example in Summary Text 4.4 is an example of behavioral application of such a bias). A parallel asymmetry in terms of avoiding potentially sick people by recognizing possible symptoms and triggering the disgust response, could account for the stigma attached to sickness and disease, even when symptoms are inappropriately attributed (Haselton & Galperin, 2012). EMT can also account for the negative weighting bias—it being potentially more costly to make false positive than false negative judgments about another person (e.g., a potential future partner), and the fundamental attributional error (FAE)—a dispositional narrative of another's behavior, having been selected to assist in avoiding undesirable social partners, being easier to construe and retain than a plethora of possible ecological accounts (Haselton & Galperin, 2012; Hasleton & Nettle, 2006). The FAE is most likely to be manifested in situations in which fitness costs are highest (e.g., where threats are greatest) such as aggression and deceit† (Hasleton & Nettle, 2006).

Contrary to much of the literature on heuristics and biases, within an EMT framework, Johnson et al. (2013) maintained that cognitive biases were adaptive and could improve DM under uncertainty. Suggesting that the numerous cognitive biases (some 150 have been identified) might be functional for DM under uncertainty, Haselton and Nettle (2006) identified evolutionary reasons for the seemingly oxymoron personality "paranoid

* Revisited in Chapter 5.

† That the notion of such cognitive biases is not a modern one may be gleaned from a translated quote from René Descartes' (1641) *Meditations*, "It is prudent never to trust completely those who have deceived us even once."

optimist" type to emerge. While under some conditions it is appropriate to be cautious ("paranoid"), in the face of different circumstances, advantage is to be gained by adopting an optimistic or R-T demeanor (Haselton & Nettle, 2006). Hence two seemingly contradictory biases can coexist. Agency bias, which could be considered to be an other-directed version of the illusion of control by oneself, could account for religious beliefs—it being safer to assume that some agency (e.g., a God that needed to be appeased or worshipped) caused an event than to attribute randomness. The illusion of control can produce superstitious behaviors that occurred, perhaps only once, or were even transmitted as narrative immediately prior to a desired event, thereby being reinforced, or before an undesired event leading to future avoidance, which can also apply to one-off adverse consumption experiences (Hasleton & Nettle, 2006).

Paralleling the visual attention bias in detecting threats in the natural environment (e.g., snakes), Schaller et al. (2007) presented evidence for a comparable threat detection mechanism for the social environment (e.g., threatening faces, people who cheat). Proposing an error asymmetry in the attribution of anger in others, Galperin, Fessler, Johnson, and Haselton (2013), Haselton and Nettle (2006), and Haselton et al. (2005) have suggested that overestimation of another's trait anger or aggressive intent would have been adaptively selected for as underestimation of conspecific anger trait would have resulted in more harm to those with this predisposition. However, misperceiving aggressive intent from in-group members could have been costly in terms of reputation loss, thereby potentially incurring other social costs (Haselton & Nettle, 2006).

A preliminary evolutionary taxonomy of cognitive biases developed by Haselton et al. (2005) is reproduced in Table 4.1. It postulates three origins for so-called biases, which these authors and others refer to (in this and later works) as design features rather than flaws.

To the possible reasons for cognitive biases to have been selected for, Johnson et al. (2013) added: (1) efficiency (bias could have been cheaper to maintain than an unbiased cognitive frame), (2) speed (bias could have

Table 4.1 Evolutionary Taxonomy of Cognitive Biases

Bias type and derivation	**Examples**
Heuristics—Mental shortcuts resulting from processing limitations, which generally work well, even if sometimes inappropriate	Stereotyping, FAE, single-reason decision strategies, conjunction fallacy
Error management—Biases arising when adaptive solutions result in lower long-term costs (e.g., reproductive fitness, health, safety)	Auditory looming, positive illusions (e.g., self-enhancement, invulnerability, agency, control, optimism, overconfidence), representativeness, males' sexual interest overperception, females' relationship commitment underperception
Artifactual—Mind not trained or designed for current task (e.g., laboratory experiment)	Confirmation bias (some instances), base rate neglect in statistical prediction (some instances)

Source: After Haselton, M.G. et al., The evolution of cognitive bias, in Buss, D.M. (Ed.), *The Handbook of Evolutionary* Psychology, Wiley, Hoboken, NJ, 2005, pp. 724–746.

facilitated faster responses compared with an unbiased response), (3) evolved capacity (preexisting neural architecture could have more readily enabled a biased approach), and (4) adaptive landscape (enabling the maximization of fitness within the current context). Another way of considering these features is to recognize biological limits imposed upon DM, which

Table 4.2 Some Adaptive Cognitive Biases in Six Domains of Interaction

Interactive domain	Examples of adaptive cognitive biases
Alliance formation	Hypersensitivity to: others' potential disease cues, unfair exchanges, and rejection cues; attenuation of these sensitivities in kinship relations
Status	Cue sensitivity indicating one's hierarchical position, especially males
Self-protection	Cue sensitivity to in-group/out-group membership and to local in-group/out-group ratio; false positive bias to potential threats from out-group males
Mate search	Attention to: fitness-linked features, age-related fertility cues (males), status (females), competitor attractiveness (females), competitor status (males), over-interpretation of sexual interest (males), conservative bias in evaluating commitment (females)
Mate maintenance	Diminished concern with equity between mates, enhanced concern with infidelity cues, hypervigilance for potential mate-poachers
Kin care	Concern with sibling equity (amplified for step-siblings), diminished concern for self-other equity in offspring interactions (except step-parents)

Source: After Schaller, M. et al., Human evolution and social cognition, in Dunbar, R.I.M. and Barrett, L. (Eds.), *Oxford Handbook of Evolutionary Psychology*, Oxford University Press, Oxford, UK, 2007, pp. 491–504.

Table 4.3 Possible Adaptive Rationale for Emergence of 15 Cognitive (Attributional) Biases

Rationale bias	Cognitive limitations	Reduce psychological threat	Increase personal control	Reduce fear	Enhance group survival
FAE	✓		✓		
Just world		✓			✓
Self-serving (defensive)		✓	✓		
Severity		✓		✓	
False consensus			✓		✓
Situational			✓	✓	
Correlational	✓		✓		
Negative weighting		✓			
Availability	✓	✓			
Adjustment	✓				
Representativeness	✓		✓		
Small numbers	✓	✓	✓		
Anchoring		✓	✓		
Overconfidence	✓	✓			
Hindsight		✓	✓		
Totals	**7**	**9**	**9**	**2**	**2**

include the speed and efficiency of processing sensory information and the lengthy temporal time frame required for adaptive capacity. Citing findings on asymmetric error outcomes in DM under uncertainty from a number of disciplines, Johnson et al. (2013) identified these as examples of risk sensitivity and as risk management in applications terms (see Chapter 11). However, Marshall, Trimmer, and Houston, McNamura (2013b) maintained that a conceptual account of the evolutionary stability of cognitive biases is still required, while Schaller et al. (2007) identified a need to understand more about how learning mechanisms evolved to generate a range of behaviors (e.g., fears and phobias).

A different framework for understanding how certain adaptive cognitive sensitivities and biases could have arisen was provided by Schaller et al. (2007), who began with various interactive domains as the basis. These authors' framework is summarized in Table 4.2.

A third way of considering possible evolutionary explanations for cognitive biases is to start with some biases and determine what type of adaptive function/s they might have served. In Table 4.3, five criteria have been identified that would be likely to have been relevant to ancestral humans: (1) cognitive limitations (e.g., heuristics—as in Haselton et al., 2005), (2) reduce psychological threat (e.g., self-protection—as in Schaller et al., 2007), (3) increase personal control (as in EMT, Haselton et al., 2005), (4) reduce fear (could be related to self-protection), and (5) enhance group survival—critical to hunter–gatherer societal structure. The extent to which each of these criteria is hypothesized to have facilitated the emergence of each bias is indicated in the respective columns. Unlike Tables 4.1 and 4.2, it is possible that more than one survival or fitness factor could have given rise to some biases.

4.16 *Driving and risk behaviors*

While risk behaviors have been studied in a variety of domains, among the most widely researched is driving behavior, particularly young drivers' greater tendency than older drivers to engage in risky driving. An early questionnaire survey of adolescents found that males had riskier attitudes than females did, and that older high-school students (16–17 years) had riskier attitudes than younger (14–15 years) students did (Harré, Brandt, & Dawe, 2000). A questionnaire-based study of adolescents' engagement in video games and traffic RPs, revealed that car racing video gaming predicted attitudes to risky driving and fun riding intent (Beullens, Roe, & Van den Bulck, 2008). Adolescents with higher intensity and physical aggression were more likely to play more driving-related video games. In a subsequent longitudinal panel survey of adolescents with a two-year time gap, Beullens, Roe, and Van den Bulck (2011) explored video gaming, speeding, fun riding, and alcohol use. Risky driving video gaming could involve scoring points by hitting other vehicles and pedestrians. From a conceptual framework that employed cultivation theory and TPB, it was found that controlling for aggression and SS, car racing video game playing predicted risky driving through attitudes toward R-T in traffic and intent to engage in this behavior (Beullens et al., 2011).

Testing a sample of young drivers, Haque and Washington (2013) found that while reaction to an external distractor within the central visual field was little affected by mobile phone use, reaction to an external distractor (e.g., pedestrian, cyclist) in a motorist's peripheral vision was significantly increased, particularly for the least experienced motorists. Expanding the study of adolescent R-T from driving, using the general learning model, socio-cognitive models, and general aggression model, Fischer, Greitemeyer, Kastenmüller, Vogrincic, and Sauer (2011) described a meta-analysis (105 independent effect sizes) exploring risk-glorifying media effects. Exposure to media glorifying R-T behavior (e.g., risky driving, extreme sports, binge drinking) was positively associated with R-T behaviors, positive cognitions/attitudes to risk, and risk-positive emotions. Effects were found for a variety of risky behaviors (e.g., smoking, drinking, driving, sex), and were stronger for active (e.g., video gaming) than for passive (e.g., film, music) activities, and when the contextual fit between media content and R-T outcome was high. Effects of risk-glorifying media on R-T were stronger for respondents under 24 years than for older respondents (Fischer et al., 2011).

An experimental study of young drivers by Harbeck and Glendon (2013) used Gray's reinforcement sensitivity theory (RST), comprising behavior inhibition system and behavior approach system elements. SEM revealed that RST variables, negative reactivity, reward responsiveness and fun seeking accounted for unique variance in young drivers' RP. Reward responsiveness and RP accounted for unique variance in young drivers' reported engagement in risky driving behaviors. Negative reactivity was completely mediated by RP in its negative relationship with reported engagement in risky driving behaviors. The authors urged the adoption of tailored approaches to identifying risk-prone drivers and developing media campaigns aimed at behavior change (Harbeck & Glendon, 2013).

Seeking to explain some young driver behaviors in terms of contemporary neuroscience knowledge, Glendon (2011a) identified a number of ways in which the development of young drivers' brains could account for some of the many empirical findings in this area. For example, the shifting balance between subcortical and cortical areas (e.g., right VS being less active in teenage brains) could lead to behaviors likely to be driven by more extreme incentives characterized by reward seeking, novelty seeking, SS, R-T, and "recklessness" (e.g., speeding, tailgating). Another example is the differential development of cortical (e.g., PFC) and subcortical (e.g., amygdala) areas, which could affect young drivers' ability to use information to make good (e.g., safe) decisions. Processing critical emotions (e.g., fear) in others at adult levels is still developing, and peer influence may be important up to age 25 years. The rate of amygdala and hippocampus development means that integrating emotions and cognitions occurs over an extended period, which could put young drivers in danger—for example, arising from an underdeveloped ability to handle stress (see Chapter 6). Subcortical regions (e.g., NA) mature before and are more active in adolescents prior to decisions involving risk. Later development of VPFC, and lower levels of activity here and in white matter linking circuits with these regions, implies a bias to immediate rewards over longer-term goals, making decisions with possible risk outcomes more likely for younger drivers. Visuo-spatial functions associated with parietal lobes mature earlier than executive PFC functions. This means that while hazards may be perceived as in adults, risk cognition (understanding the nature of hazards and their potential for harm) lags behind. Areas of the brain responsible for creating mental imagery (e.g., insula, right fusiform face) are still developing. This could result in delays in processing critical information about generically dangerous situations—younger drivers take longer to process such information. Glendon (2014) expanded on these and other aspects of neural development to identify a series of features that could assist young driver education and training.

The social context of driving is also important, particularly for young drivers, with peer influence prevalent among the topics studied. Using a delay discounting task offering a choice between a smaller reward now versus a larger one in six months, O'Brien, Albert, Chein, and Steinberg (2011) revealed a greater preference for immediate rewards when adolescents were in the presence of peers, due to the effect on reward sensitivity. Adopting an fMRI methodology during simulated driving, Chein, Albert, O'Brien, Uckert, and Steinberg (2011) found that peer presence (not pressure) increased R-T (e.g., in driving, crime, and substance abuse) in adolescents but not in adults. Peer presence sensitized brain regions anticipating (incentive) reward, particularly the VS (NA and other structures) and the OFC. Cognitive control brain regions (e.g., LPFC) were less strongly recruited by adolescents (Chein et al., 2011). Behavior was significantly predicted by SS but not by impulsiveness. The main effects of age (greater activation) were in the left middle frontal PFC, left inferior parietal, left middle temporal, and left fusiform areas. The main effect of peer presence was represented by activity in the left cuneus/superior occipital, precuneus, left superior frontal, cingulate, and right middle temporal regions (Chein et al., 2011).

4.17 Wider considerations: Global and group levels

Several expanded considerations of risk and safety are discussed in more detail in Chapters 6 through 11. Here we identify a few further issues relevant to threat appraisal and risk perception.

As countries become more wealthy, disease threats change from infectious to noncommunicable types as a result of improved medical care, population aging, and public health interventions such as clean water, sanitation, and vaccinations (WHO, 2009). As noted by the WHO (2009), population-wide health strategies involve shifting the responsibility of addressing large risks from individuals to government and health agencies, thereby acknowledging that socio-economic variables are major contributors to adverse health outcomes. The WHO (2009) identified 24 risk factors that substantially contributed (44% of global deaths) to the 2004 disease and injury mortality burden. Selection criteria for these risk factors were

- Potential global impact
- High likelihood of direct risk-disease causal relationship
- Potential for modification
- Neither too broad nor too specific
- Reasonably complete data available (e.g., peer-reviewed research)

The list of 19 leading global risk factors identified by the WHO (2009) is headed by high blood pressure, tobacco use, high blood glucose, physical inactivity, being obese/overweight, and high cholesterol, all of which contribute to deaths in all country types (i.e., high-, middle-, and low-income countries). Most of the remaining risk factors apply mainly or exclusively to low- and middle-income countries, and are headed by unsafe sex, alcohol use, childhood underweight, smoke from indoor fuel burning, unsafe water/sanitation/hygiene, low fruit/vegetable intake, suboptimal breastfeeding, urban air pollution, occupational risks, and vitamin A deficiency. While readers will be very familiar with the risk factors listed in the first sentence of this paragraph, those in the second sentence might be surprising. These relative risk factors reveal the very different everyday experiences and exposures that people in different countries face in the contemporary risk landscape (WHO, 2009).

While human evolution initially selected for skin color on the basis of geographical and climatic conditions, the ease of travel in our modern world has allowed many people to live

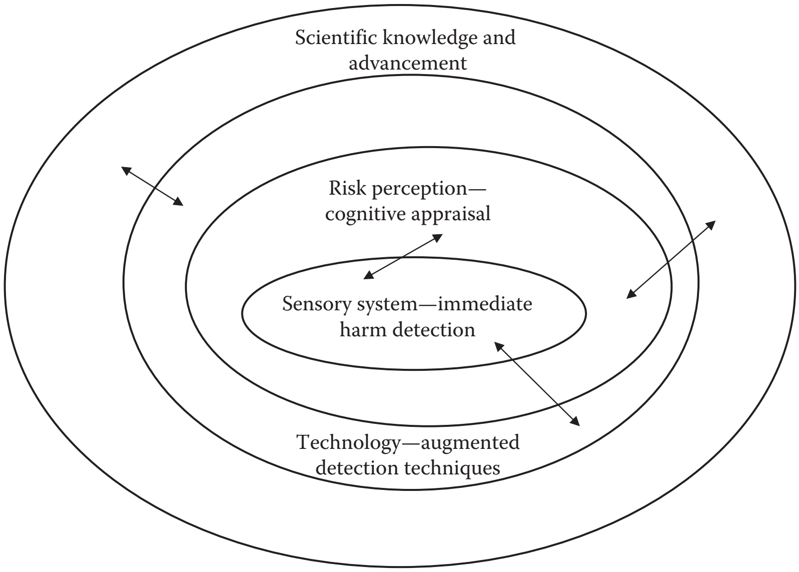


Figure 4.2 Humans' harm protection system. Arrows represent information flows between levels–for example, risk communication media.

in locations that help to maintain the body at a comfortable temperature. Contemporary lifestyles have subsequently generated new dangers, for example, fair skinned migrants to Australia and other warm climes are at increased risk of skin cancer from exposure to the sun's UV rays. With advancing technology, it is possible that in wealthy countries, based on their capacity to process sensor-based data deemed to be relevant to human health and safety, algorithms might increasingly be employed to make decisions about risk (e.g., in self-driving vehicles). However, as with many examples of previously introduced technologies, such automated systems are liable to generate new forms of risk.

Figure 4.2 illustrates in simplified form the relationship between individual sensation of danger and the perception of risk, which may also be perceived at a group level. Illustrations include workgroups in which an individual may have a designated watching role, for example, as in track workers in the rail industry or the miners in Gouldner's (1955) classic study. Alternatively, all group members may share a hazard watching role, as in soldiers on patrol or airline flight crews. While autonomous groups may be able to manage their own risks, at the collective level, as in an organization, formal processes exist for managing risk, which are explored further in later chapters.

chapter five

Reframing error

5.1 Introduction

To avoid triggering our full wakefulness state, probably all of us have chosen not to switch on a light during nighttime bathroom visits. On such occasions glancing at our shape in the mirror, we have recognized our body outline without needing to incorporate detail. However, if we were to spend some minutes examining our face under these conditions, we might be surprised, and even alarmed, at what we "see." Lacking visual information about our features that we take for granted during daytime, our brain attempts to make sense of the available information to construct a picture of a face. However, as the minutes pass, it is not our face that we see but that of a stranger, or perhaps more frighteningly, of some witch or demon with gargoyle-like features.* Does this constitute a perceptual error? Is it a "human error?" What is going on? Summary Text 5.1 provides a little more information.

Driven by our powerful survival motivation to understand and control the world around us, our brain is configured to interpret available sensory information. The sparse input available in the quiet darkness, therefore, stimulates our brain to make sense of what is available and particularly to draw our attention to any potential threat. Being primed to interpret danger under quiet low-light conditions, taking no chances the brain provides us with a picture that represents potential threat. This powerful "perceptual error" is analogous with those generated by visual geometric illusions, which are anathema to the brain's need to make sense of the environment. In these cases, it switches between possible interpretations so as to offer us the choice of which to accept as the "true" picture. In cross-modal illusions, such as the ventriloquism or McGurk effects, the brain is similarly driven to produce a credible overall picture of events. Thus, what may be called *perceptual errors* often reflect our attempts to make sense of our immediate environment by maximizing the use of available stimuli with the key motivation being survival or "evolutionary fitness." As information overload narrows the brain's focus to what it perceives to be most relevant to current performance, the information available from attenuated sensory input will be amplified, and perhaps distorted, to produce a view of the world that makes sense to the perceiver. Thus, what may on one level be construed as errors may need to be understood within a broader adaptive framework.

From an evolutionary perspective, competitive advantage for both predators and prey species has accrued by reacting very quickly according to a number of estimated parameters, for example, because of ambiguous visual or auditory received stimuli. Compared with a slower response that always produces a perfect result, both escape survival and prey capture are more likely when a rapid response is achieved at the expense of occasional imperfect performance. A second principle is that using several parallel "rough

* If you try this at home we suggest that you set a timer to ring at say 10 minutes to terminate the experiment. The first author's particular gargoyle had a grossly exaggerated open mouth, black slit eyes, and no nose. Eventually this was accepted as a reasonable approximation of the real thing!

SUMMARY TEXT 5.1 Faces Are Everywhere!

Apophenia, the general form of the phenomenon of seeing patterns in random data or ambiguous stimuli, is the basis of the well-known Rorschach inkblot test. The well-documented version of this phenomenon by which we tend to see faces in ambiguous stimuli is face pareidolia and is hypothesized to be a hard-wired adaptive feature that allows us to rapidly recognize potential threats. While the cortical response to actual faces can be triggered at 130 ms after stimulus onset, objects incidentally perceived as faces can activate the ventral fusiform cortex (fusiform face area) at 165 ms, suggesting that such a response is an early rather than a reinterpretative process (Hadjikhani, Kveraga, Naik, & Ahlfors, 2009). Individual and group differences in attributing faces where none exist have been associated with particular belief systems (Riekki, Lindeman, Aleneff, Halme, & Nuortimo, 2012). Amygdala hyperactivity has been found to play a key role in responding to angry or fearful faces in individuals with generalized social anxiety disorder and social phobia (Cooney, Atlas, Joormann, Eugène, & Gotlib, 2006; Evans et al., 2008; Phan, Fitzgerald, Nathan, & Tancer, 2006). While socially phobic individuals have been revealed as more likely than those without this condition to misclassify neutral facial expressions as angry (Bell et al., 2011), a sample of individuals with generalized social anxiety disorder were found not to show a threat-related bias when interpreting ambiguous facial affect (Jusyte & Schönenberg, 2014).

The phenomenon of perceiving distorted versions of actual faces is less well understood but has generated interest via YouTube videos showing how the effect can be manipulated by viewing a spot between two attractive (either well-known or unknown) faces flashed in pairs (the flashed face distortion effect). The illusion can be seen at TangenCognitionLab (2011, 2012).

It is possible that when the faces are not viewed frontally, seeing two faces in the visual periphery activates a threat circuit as a protective biasing effect.

and ready" methods to reach a conclusion (e.g., action decision) is more likely to optimize performance compared with following one method very accurately (Crick & Koch, 2003). These simple evolutionary principles are the foundation for human action—and for so-called *human error* (HE). Where insufficient information exists to generate an unambiguous interpretation of someone's environment, cortical networks complete the picture using "best guess" estimates, which may constitute the basis for all cognitive biases (cf. Chapter 4). Therefore, the various observations that have been designated as varieties of "HE" need to be understood within a lengthy historical perspective that may pay scant regard to some modern-day tasks. Human performance may be driven by very different principles that govern the complexity of our contemporary world. Our error legacy is motivated primarily by the behaviors that were most likely to have guaranteed our individual and collective survival.

This chapter is broadly organized to consider initially some of the known neural correlates of error performance. It then addresses some key cognitive components of what has come to be called "human error," before reviewing some wider implications, including one attempt to understand and address HE, situation awareness (SA).

5.2 Neural correlates of error performance

Skilled performance requires continual monitoring to detect errors and responding appropriately when an error is detected. In considering the role of errors during skilled performance, Maidhof (2013) reinforced the importance of error awareness (conscious error detection) for learning to occur. In electroencephalography (EEG) studies, error detection and compensation has been consistently associated with error-related negativity (ERN)—a sharp negative deflection in the event-related potential (ERP) 20–150 ms prior to an incorrect response (error), which compared with correct actions occurs at a lower velocity and more slowly (posterror slowing [PES]). It, therefore, appears that errors are detected predictively (Maidhof, 2013; Ruiz, Strübing, Jabusch, & Altenmüller, 2011). ERNs appear to be generated either in the dorsal ACC (dACC; Maidhof, 2013; Orr & Hester, 2012) or in the rostral cingulate zone (RCZ) within the posterior medial frontal cortex (pFMC; Klein et al., 2007). RCZ/pFMC activity appears to signal the need for posterror adjustments (Klein et al., 2007).

It has been suggested that covariation in the ERN with error awareness (Klein, Ullsperger, & Danielmeier, 2013) may reflect either response conflict/competition (Carter et al., 1998), or thwarted reward expectations, or detected changes in error likelihood (Orr & Hester, 2012). Arising in the PFC and parietal cortex, a comparable positively deflecting ERP has been observed 100–400 ms following an aware error (Klein et al., 2007; Orr & Hester, 2012; Ullsperger, Harsay, Wessel, & Ridderinkhof, 2010), representing recognition that an error has been committed (Harsay, Spaan, Wijnen, & Ridderinkhof, 2012).

Aware (but not unaware) error detection is associated with activity in the ACC (Posner & DiGirolamo, 2000), which is also activated by conflict. ACC activity is also related to planned behavior (Posner & DiGirolamo, 2000) and has a monitoring function with respect to actions (Petersen & Posner, 2012). Studies have indicated the predominant role of the left anterior insula (AI) in monitoring behavior, including error awareness (Craig, 2010). Studying performance errors in a repetitive task to identify brain activation patterns that preceded errors implicated specific brain regions in which activity predicted error commission: (1) bilateral AI/ACC, suggesting a performance monitoring function and (2) right AI/inferior frontal gyrus (IFG) and a medial prefrontal cortex (MPFC) region near the ACC, associated with evaluating task costs and maintaining task effort. In the latter regions, activation declined just before an error occurred and increased following an error, similar to the pattern of attention-related activity in the study of attentional lapses (Craig, 2009). As well as error detection, the medial frontal/ACC and AI system is involved in diverse processing tasks, including pain perception (physical and social), reward, and conflict monitoring and resolution (Petersen & Posner, 2012). While both 7-month-old infants and adults use the ACC in error detection, the usual PES response does not appear until around 3 years of age (Petersen & Posner, 2012).

The MPFC has also been associated with conflict responses, impulsive behavior, and autonomic activity (Craig, 2009). Contrasting brain activity during aware errors with that during unaware errors, activation only in the left inferior AI was found (Klein et al., 2007). These authors suggested that AI activity during error awareness might be explained by interoceptive awareness of greater autonomic responses to aware errors. AI activity and error awareness might precede the autonomic response (Klein et al., 2007). An empirical study contrasting error awareness in brain-injured and uninjured samples is outlined in Summary Text 5.2.

Numerous reviews and studies have identified the importance of the ACC in error monitoring and responding (Bush, Luu, & Posner, 2000; Carter et al., 1998;

SUMMARY TEXT 5.2 Error Awareness

The material in this account is taken from Hart, Giovannetti, Montgomery, and Schwartz (1998).

In Hart et al.'s (1998) study, error awareness in brain-injured and matched uninjured samples was measured by self-report, therapist observation, and at four levels of task performance. The type of awareness studied was akin to the situational or "online" variety considered later in this chapter. Eight types of commission errors (sequencing, substitution, incorrect gesture, spatial misestimation, spatial misorientation, tool/utensil omission, irrelevant actions, quality errors) were summed to give a total task error score. Omission errors were also scored.

Noting that awareness is seldom an "all-or-nothing" phenomenon, the authors found that global awareness (i.e., environmental attentiveness) was high in both samples, indicating that this type of awareness could not account for any between-group differences. Both groups had a very high awareness of events—97% in the case of the brain-injured sample. However, while participants occasionally demonstrated awareness of an error without making any attempt to correct it, awareness scores and error corrections were highly correlated, and brain-injured participants were aware of a significantly lower percentage of their errors.

Anticipation errors, in which a task step is performed too early so that another step is omitted or delayed, were the most common type. Control participants were aware of all such errors (10) and brain-injured participants were aware of the majority of these errors (11/13). However, for the second most frequent error type—object substitutions or misplacements—controls were aware of 5 of their 7 errors, while brain-injured participants were aware of 3/12. Sequencing errors were generally detected by both groups, while object use errors were more frequently detected by controls, which the authors suggested might have reflected the feedback generated by each type of error. Thus, anticipation errors, which caused problems later in the task, had a salience effect, while object substitutions might not be detected if the task could be completed apparently successfully with a substitute object.

The study revealed that error awareness was not a unitary phenomenon, and notwithstanding the well-known increase in error detection and correction that accompanies greater task expertise, different error types were liable to generate different degrees of awareness.

Dehaene, Posner, & Tucker, 1994; Maidhof, 2013; Orr & Hester, 2012). The right ACC is involved in monitoring errors and signaling need for control (Zayas, Mischel, & Pandey, 2014). Also involved in error awareness are the pFMC, particularly the RCZ, the pre-supplementary motor area, the bilateral inferior AI, and the thalamus (Klein et al., 2007, 2013). Error processing may occur either with or without conscious awareness. While RCZ activity did not discriminate aware from unaware errors, left inferior AI activity, associated with increased autonomic activity, was stronger for aware than for unaware errors (Klein et al., 2007).

Action monitoring theories suggest that the pFMC, particularly the ACC, detects errors, before signaling the need for increased cognitive control to the lateral PFC

(LPFC), which adjusts performance (Ruiz et al., 2011). Various theories, including neural representation comparison, reinforcement learning, and conflict monitoring, attempting to explain how the ACC might monitor errors to improve learning skilled performance were reviewed by Maidhof (2013). Hypotheses about how errors are consciously recognized include error awareness, behavior adaptation, and affective processing (Maidhof, 2013). Unsurprisingly, several pathological states, for example, induced by various drugs or clinical conditions affect error awareness adversely (Carter et al., 1998; Klein et al., 2013; Ullsperger et al., 2010).

While the ACC and AI are involved in error processing, it appears that only the AI is involved in error awareness (Harsay et al., 2012). The dACC has been associated with error-related autonomic arousal (e.g., change in heart rate, skin conductance, pupil dilation). Autonomic arousal and PES were reduced or absent during unaware errors (Orr & Hester, 2012). While the ACC and AI are frequently coactivated as part of the salience network, including error processing, the AI is more attuned to receiving multisensory input, while the ACC is part of the action-orientation network (Bush et al., 2000; Harsay et al., 2012). Regions that Orr and Hester (2012) found were activated to differentiate aware from unaware errors were the bilateral inferior parietal lobe (IPL) and left supramarginal gyrus, left dACC, bilateral insula, left midcingulate/presupplementary motor area, and left supplementary motor area. Using a different task paradigm, regions that Harsay et al. (2012) identified as differentiating between aware and unaware errors included right AI, dACC, bilateral pre- and post-central gyrus (somatosensory cortex), bilateral frontal eye fields, superior parietal lobules, and bilateral thalamus. As a region that is involved in selecting and evaluating goal-directed actions, an indirect relationship between the dACC and error-related behaviors was postulated by Orr and Hester (2012).

The AI may facilitate affective error-based learning to assist successful decision making (DM) under uncertain conditions (Bernhardt & Singer, 2012). Ventral and dorsal attentional regions concerned with error detection are also involved in a range of cognitive processes, including conflict monitoring, interference resolution, response selection and inhibition, problem solving, DM, and performance monitoring and include the AI, ACC, and dorsolateral prefrontal cortex (DLPFC) (Eckert et al., 2009; Sridharan, Levitin, & Menon, 2008). Functioning on the border between perception and action, mirror neurons work with the superior temporal cortex to generate a map of intentional states that allows an individual to determine their next action (Siegel, 2009).

As a prime register of interoception (Craig, 2009), the insula provides affective and autonomic components of error awareness leading to an orienting response (Klein et al., 2013; Ullsperger et al., 2010). As part of the frontoparietal control system, the IPL has a cognitive control role in maintaining sustained attention to a task and is associated with posterror adjustment. Activation of the motor regions is likely to reflect motivational and action components of a task, including intention, preparation, and initiation of an alternative response following a performance error (Orr & Hester, 2012). Motivated behavior assigns values to objects/events that are either rewarding or punishing. As well as links with sensory processes, there appear to be generalized responses to a range of hedonic and painful stimuli (Breiter & Gasic, 2004). Significantly faster RTs for aware errors were consistent with the hypothesis of higher response conflict increasing ACC activity. The adaptive function of error awareness was revealed by subsequent performance improving as a result (Orr & Hester, 2012).

Further differentiation of the role of the insula in error processing was developed in a meta-analysis (55 studies) by Ullsperger et al. (2010), who distinguished between the role of the dorsal AI (dAI), which appears to signal increased risk through anticipation of an imminent error, and the ventral AI (vAI), which appears to register error prediction. By recruiting resources to preempt potential risks and failures, the dAI therefore functions as a prospective control mechanism, while by monitoring the need for remedial action and regulation, the vAI is more geared toward reactive error processing (Harsay et al., 2012; Ullsperger et al., 2010). Activation in the vAI has also been associated with peripheral physiological responses (heart rate change, skin-conductance response) and their emotional correlates (Harsay et al., 2012). By mapping arousal, the AI ascribes emotional significance to deviant targets, including errors, and initiates integration of salient information into DM to guide behavior (Harsay et al., 2012).

Errors through concentration lapses are well known in many tasks requiring extended periods of vigilance (e.g., long-distance driving, control room monitoring). While some errors in such tasks may be generated by random fluctuations in neural activity during performance, others may result from more systematic cognitive control maladjustments that develop over time, which may be more predictable. Two well-documented effects on extended task performance are fatigue—a decline in task-related effort and control and distraction—or interference with task performance through suppression of task-related neural activity (Eichele et al., 2008). These authors identified negative correlations between effective task performance and activity in the brain's default mode network (DMN), comprising the precuneus, retrosplenial cortex, and anterior medial frontal cortex (Eichele et al., 2008). They determined that maladaptive brain activity associated with performance errors could be detected up to 30 s before an error occurred. This consisted of increased DMN activation and decreased activity in brain regions associated with maintaining task effort (Eichele et al., 2008). While economizing on task effort might have been adaptive for ancestral humans, in many tasks involving contemporary technology, outcomes may include increased error likelihood. Indeed, the authors interpreted their finding as representing a gradual change in brain activity designed to economize on task performance, implicating the pFMC in monitoring errors, conflict, and feedback (Eichele et al., 2008). Using this knowledge, they recommended developing monitoring devices to alert operators engaged in monotonous tasks in which gradual disengagement is difficult to avoid.

Error monitoring, and more general performance monitoring, is less reliable in adolescents compared with adults because the ACC is less robustly engaged in adolescents, which leads to a higher likelihood of inhibitory control errors (Luna, Padmanabhan, & Geier, 2014). In addition, the neural circuitry that supports sustained attention (e.g., PFC, inferior parietal sulcus) is less engaged than in adults, thereby limiting adolescents' ability to establish a controlled cognitive state to match adult performance. It is conjectured that these error-inhibiting limitations result from immature top-down control processes supporting executive control (Luna et al., 2014).

Risk prediction, associated with uncertainty and expressed as reward variance, has been distinguished from risk prediction error—used to improve future risk prediction (Preuschoff, Quartz, & Bossaerts, 2008). AI activation has been correlated with both risk prediction and risk prediction error, as well as with stimulus complexity, ambiguity, and uncertainty. Risk processing in the AI appears to have at least two components. Fast-onset AI activation was associated with risk prediction error (outcome), which may mediate learning, while late-onset activation anticipated potential risk (Preuschoff et al., 2008). These authors suggested a dual role for risk estimation: first is as a choice guide in all risk-sensitive decisions and second is to modulate learning of expected rewards (via subcortical dopaminergic and other neurotransmitter responses). Risk may thereby generate positive value through discovering new opportunities (Preuschoff et al., 2008).

Postulating two complementary strategies to represent the world, Singer (1998) identified the first as individual neurons being tuned to particular constellations of stimuli being rapidly processed and ideally suited to representing high-frequency feature combinations. This strategy would be best suited to adherence to safety rules in predictable environments. The second strategy involves temporary associations of neurons being tuned to one elemental feature within a complex perceptual field, which would be neurally more flexible and efficient as individual neurons could participate in different assemblies (Singer, 1998). This pattern would be particularly well suited to representations of highly complex and permanently changing environments, for example, novel situations in which safety rules may not apply and knowledge-based approaches are required. It is thereby possible to identify hypothesized neural underpinnings for well-established human factors (HF) models, in this case rule-based and knowledge-based aspects of performance.

Neuroimaging studies have delivered numerous insights into how human performance incorporates error monitoring, as well as how errors are detected and corrected. However, limitations of experimental work mean that these insights have so far been restricted to enhancing our knowledge of the neural correlates of skill-based and rule-based errors. It seems that while detecting and correcting skill-based errors mainly employs ACC-oriented circuitry, the AI is a prime focus for rule-based error awareness and correction. Because of their importance as learning opportunities, errors are processed as features of the brain's salience network by triggering an orienting response, which engages attention and directs the organism to change behavior. Widely distributed activation of brain circuitry in response to salient events, even rarely encountered ones, can be construed as an adaptive feature that facilitates learning and subsequent performance. Coupling neural, cognitive, physiological, and emotional responses to errors (and other salient events) allows for optimal behavioral adjustments (Ullsperger et al., 2010). However, because the network of brain regions that is activated during error processing differs between tasks, further insights are awaited into how different error types are more finely differentiated at a neural level.

Understanding how knowledge-based errors are represented neurally will require considerably greater resources and ingenuity than has been available to date. It has been suggested that error monitoring is hierarchically arranged within the CNS, so that, for example, errors that interfere with reward achievement or abstract high-level goals are processed in the salience network (pFMC, particularly the RCZ, AI, and adjacent frontal operculum/OFC) to recruit resources in response to errors (Ullsperger et al., 2010). Whether the same neural networks as have been identified in experimental tasks are also involved in knowledge-based errors or whether more complex brain circuitry is involved remains problematic. Representing the complexity of unfolding disaster scenarios, for example, using sophisticated simulation techniques, in addition to collecting neuroimaging data, remains an important challenge for future research.

From an applications perspective, it is increasingly likely to be necessary to distinguish between operator engagement in tasks in which nearly all errors are detected and corrected and experimental tasks in which no more than 50% of errors are detected by participants (Ullsperger et al., 2010). Simulating a range of safety-critical real-world tasks and collecting neural imaging data corresponding to task engagement could assist in tracking critical task components as well as the neural correlates of different error types to indicate design changes and training programs to minimize error likelihood.

5.3 Cognitive features of error

5.3.1 Attention and attentional lapses

The close relation between attention and action means that vision-to-action processes are rapid and automatic (independent of intention), having evolved to aid prey search and avoid predation. Rapidly encoded action can influence visual attention (e.g., guiding search). Objects can evoke actions in parallel with, and interfere with, goal-directed behavior. Inhibitory feedback processes that act on competing actions have evolved to solve the selection-for-action problem (Tipper, 2004). Prehension (reach) is guided by body-centered frames in the medial intraparietal cortex to dorsal premotor cortex, and a second system based on object shape encodes grasping information through the anterior intraparietal cortex to the ventral premotor cortex. Automatic visuomotor processing results from interactions between dorsal and ventral visual streams. The ventral stream specializes in consciously recognizing objects in the visual scene (e.g., by color); the dorsal stream specializes in visual guidance for action (e.g., saccades, pointing, reach to grasp), which may be unavailable to conscious awareness (Tipper, 2004). If a prime (which automatically triggers the assigned motor response) and target are inconsistent, reach initially starts in the wrong direction (path deviation) and is corrected online. Action affordances (action properties of a stimulus—e.g., a shape that indicates a particular function) can influence visual search (e.g., in a cluttered environment). Exercising free choice requires effective capacity to resist the strongest response of the moment. Distractor interference effects are determined by the relative ease (e.g., speed) of response. Negative priming effects evoke competing responses. An example of dual attention mechanisms is excitatory feedback processes directed toward a target and inhibitory feedback processes directed toward a distractor. Negative priming occurs if prior inhibitory processing (e.g., for a different object or feature) is retrieved. Selection is made from overlapping population codes (e.g., categories of objects) located in the cerebellum, parietal cortex, dorsal premotor cortex, and primary motor cortex (Tipper, 2004).

Traditional goals of attentional selection include locations, objects, and attributes. Selectivity of scale occurs with hierarchically organized stimuli (e.g., nested features within a control console), and it takes time to reset attention from one level to another. While the strong bias to attend to objects as wholes means that responses may be faster at the global level, this "global preference" can be modulated by local features (e.g., size, density). There may be a relative preference for selecting the higher or lower spatial frequencies in a display, which may be linked to a neural asymmetry favoring higher frequencies in the left hemisphere and lower ones in the right. Attentional limits arise when two (or more) competing tasks require the same specialized system for their performance. The greater the similarity between the two tasks, the greater the level of interference (Treisman, 2004). Inhibition is applied when distracters would otherwise interfere with a task, while selective activation is otherwise sufficient. Two very different simultaneous tasks (e.g., using different sensory modalities) could often be undertaken without performance impairment (Treisman, 2004). Tasks requiring high levels of attentional capacity for extended periods are ideally automated.

Typologies of attentional mechanisms have included (1) selection, orientation, and alertness (Petersen & Posner, 2012); (2) selection, capacity, and alertness (Posner & Boies, 1971); and (3) selection, control, and vigilance (Parasuraman, 1998). Linked to alertness, vigilant attention involves a half-life measured in seconds rather than minutes and is most sensitively measured in routine action situations (Robertson & Garavan, 2004).

A signal passed at danger is the most common form of railway incident (Edkins & Pollock, 1997), most of which do not end in tragedy because of good fortune or safety backup systems. Noting that the most important factor in such accidents is imperfectly sustained attention, Robertson and Garavan (2004) observed that "When train drivers pass through warning or stop signals as they do thousands of times per day throughout the world, this is an example … of an inefficiency in the functioning of a right hemispheric, frontoparietal attention system for 'vigilant attention'" (p. 631). Routinization of a task such as driving a train minimizes the need for the driver to engage in effortful attention. The 1996 Watford Junction train crash involved a driver passing a red signal obscured by trees and bushes. He did not recall the two prior warning signals. This error type is a skill-based slip (Reason, 1990). Two contrasting scenarios are described in Summary Text 5.3.

Everyday action error likelihood links to specific brain activation patterns (Robertson & Garavan, 2004). Arousal involves the cholinergic basal forebrain, the noradrenergic (particularly right hemisphere) locus coeruleus (LC), the dopaminergic median forebrain bundle, and the serotonergic dorsal raphe nucleus, midbrain reticular formation, intralaminar and other thalamic nuclei, AI, and frontoparietal areas. The relationship between arousal and vigilant attention is complex. Optimum task performance seems to occur at intermediate levels of arousal (LC activity). Sustained attention may be inappropriate for tasks that actually require sustained performance, which may make relatively limited demands on vigilant attention (e.g., car driving).

Vigilance involves the thalamus, substantia innominata, putamen, and right frontal and parietal areas. Right frontoparietal regions are needed to modulate arousal, particularly when not externally generated by task demand or stimulus. The ACC may interface cognition and emotion, serving as a conduit by which the right PFC–parietal system moderates arousal levels. The broad mesencephalic arousal system operates in concert with a predominantly right hemisphere frontoparietal vigilance attention system. The right PFC plays a role in the endogenous components of this system, while the inferior parietal cortex is commonly activated by both endogenous and exogenous pathways. Meta-analysis revealed that right inferior parietal lobule activation was negatively correlated with the number of errors committed. Parietal activation for both errors and successful inhibitions suggested that it has a more general attentional role in task performance. The right prefrontal area is probably critical to response selection (Robertson & Garavan, 2004).

The right inferior parietal cortex has a role in the routine, semiautomatic maintenance of sustained vigilant responding. The right DLPFC has a more executive role in maintaining vigilance, for example, engaging the vigilant state based on a dynamic assessment of the optimum arousal level to match performance with task demands. Monitoring endogenous arousal levels and task performance provides crucial information for the vigilant attention system. The monitoring function is performed by the right PFC with inputs from midline structures to detect errors or response conflicts. Vigilant attention is maintained by the right parietal–prefrontal network and its interactions with the midbrain arousal systems. The PFC has a central role in maintaining and monitoring optimum arousal levels to match current task demands. Vigilant attention might constitute continuous inhibition of task-irrelevant stimuli (Robertson & Garavan, 2004).

Lapsed attention often results in occupational and vehicle incidents and injuries. Working memory can effectively deploy attention to recently attended objects. Practice (e.g., in driving) is needed to fully develop this attention–memory combination skill. Understanding the driving environment develops from experience. For example, driving experience develops the practice of attending not just to the vehicle immediately in front but also to those behind, to the sides, and further afield. This skill is also relevant to

SUMMARY TEXT 5.3 Two Contrasting Scenarios

Scenario 1: A train driver drives 100 times through a light that is green, and if it is yellow on the 101st time and the inhibitory response is not activated, then the driving task continues. If a yellow light is detected and the accelerator handle is released in readiness for the next possibly red light, then the right dorsolateral prefrontal and inferior parietal cortices, along with thalamic and mesencephalic circuits, have been appropriately activated. However, arousal is diminished in the context of highly practiced unchallenged actions, which dull responsiveness to the environment and blunt vigilant oversight of performance. To protect against such a potentially dangerous diminution of awareness and monitoring, a right hemisphere cortical network and a subcortical arousal network has evolved, which is needed in daily tasks because much of our behavior is habitual and automatic (Robertson & Garavan, 2004). While minor inefficiencies are by definition consequence-free, on occasion, such lapses can be an important component of a major incident.

Scenario 2: At a time when his regular return commute journey included 19 traffic lights (some encountered in both directions), the first author made observations on 18 separate return journeys randomly selected over a 15-week period, noting the color of the traffic lights at each approach using consistent criteria. Of the 342 individual observations, on 209 occasions a light was green (61%), while it was red on the other 133 occasions (39%). For the 19 traffic light events on observation days, the percentage that were green on approach ranged from 19 (100%) to 1 (5.3%). One that was always green was at a T-junction on a dual carriageway main road, while the one that was red on all but one occasion required a turn against the traffic flow at the exit of the author's residential estate. For the sample of 18 journeys, the number of green lights varied from 16 (84%) to 8 (42%). Across all journeys, the longest number of red lights in a sequence was four, which happened three times, while the longest sequence of green lights during any journey was ten (the maximum possible), which occurred only once.

The main differences between the train driving and car driving scenarios is that while the train driver's experience overwhelmingly primes the expectation for a green light (Edkins & Pollock, 1997), because of the considerable variability in their daily driving experience, the car driver has no such primed expectation across all traffic light experiences. While certain traffic lights might come to generate certain expectations, for example, the one at the exit of a residential estate that has no through traffic, in general, the car driver is primed to expect either a green or a red (or an amber) light as being more or less equally likely. Another critical difference between the car driver and the train driver's experience is the existence of multiple other cues in the former's environment, which mainly take the form of other traffic, for example, adding multiple red brake lights when traffic is backed up at a red light, often making it impossible to do anything but stop. Thus, while car drivers may run red lights at a certain frequency and with a bias toward certain locations (e.g., on relatively high-speed roads when the traffic light is sited at the bottom of a slope), the circumstances under which these events occur (e.g., mistiming the length of an amber sequence, or being part of a line of vehicles passing through an amber light) are quite different from those that predispose train drivers to pass signals at danger.

In contrast to making a response to a target stimulus, train drivers must inhibit their ongoing behavior in response to a rare target (a red signal). Making a response to a rare target can facilitate performance as the target orients attention to its presence. However, research has shown that withholding a response (e.g., driving a train) to a stimulus is more difficult than generating a response (e.g., depressing a brake pedal). The attentional system is differentially engaged by both endogenous and exogenous activation. The right parietal cortex may be a common pathway for both endogenous and exogenous routes, while the right frontal cortex might be particularly linked to endogenous activation. When an inhibit target is relatively rare (11%), proportionately more errors are made than when it is more common (25%) and the error rate declines as the target rate increases to 50% (akin to traffic lights encountered frequently during road driving). More frequently appearing targets provide greater exogenous support for the task as the inhibit response is activated more frequently. When the inhibit responses are rare (e.g., red signals), exogenous support is relatively weak so that the vigilance system must be endogenously maintained, which is an important function of right prefrontal areas. Everyday action error likelihood links to specific brain activation patterns (Robertson & Garavan, 2004).

---

monitoring tasks, as in control rooms. Two attentional components seem to operate: first is a weak sustained component that is related to knowledge of the target location; second is a stronger (~2× the sustained component) transient component, which rises and quickly falls. The transient component is not a reflex as it is flexible and can rapidly learn simple (nonintegrative) first-order relations and can show dramatic changes in accordance with past experience. Transient attention—a powerful brief heightening of visual processing that seems to require an exogenous cue—has stronger benefits than sustained attention and appears to be uncoupled from higher-order knowledge of a target's upcoming location. The associated learning, which seems to be modulatory activity that activates or suppresses specific neural circuits that have been very recently activated, is flexible, temporary, and not synonymous with working memory, being more like priming. It is likely to occur in frontal, parietal, and midline structures (Nakayama, Maljkovic, & Kristjansson, 2004).

5.3.2 Change blindness

Many instances have been recorded of observers looking but failing to "see" important changes in their external environment. The generic reason for this phenomenon is that at any given moment, our limited visual capacity means that we can only perceive a subset of elements in any scene (attentional blindness), with remaining elements being accessible either by top-down driven attentional processes or by bottom-up saliency effects (e.g., attention-grabbing alarms). Thus, our perception of any scene is always deficient in some aspects. O'Regan and Noë (2001) reported a celebrated experiment in which 2 out of 8 experienced airline pilots failed to see a plane on the simulated runway in the path of their designated landing, so that they flew straight through it. Change blindness experiments might shed light on the oft-reported "looked but failed to see" phenomenon. Ways in which participants' natural ability to recognize change in the environment might be deceived have included: (1) superimposing a very brief global flicker over the whole visual field at the moment of change; (2) making the change coincident with an eye saccade, or a blink, or a film sequence break; and (3) creating additional extraneous distributed transients. In the first two cases, a brief global disturbance could swamp the local change transient so that attention was not drawn to it. In the third case, attention would likely be drawn to an incorrect location. Change blindness can occur in the event of the suppression of cues such as motion, which would otherwise generate an attentional shift, resulting in a restricted perceptual focus so that even major changes in the environment may not be noticed (Posner & Rothbart, 2009).

These phenomena are a reminder that attention is not synonymous with awareness (O'Regan & Noë, 2001). However, as noted by De Graaf, Verfaille, Germeys, Gysen, and Van Eccelpoel (2001) in their rejoinder to these authors, change blindness disappears entirely when one has advance warning of the nature of the change, that is, when given an appropriate prime. A comparable point made by Lamme and Landman (2001) is that change blindness can be largely eliminated by the expedient of providing a cue following an initial stimulus offset (e.g., a picture) and prior to the onset of a modified version. These authors accounted for change blindness by the original stimulus being overwritten as soon as a new stimulus appears, and because what remains of the original scene has been transferred to working memory, attentional capacity is required for recall and comparison. While the extent to which parallel mechanisms occur in other sensory modalities has yet to be determined, accounts of unnoticed alarms suggest that this phenomenon is not restricted to the visual sense. A classic way of countering a possible shortfall in detecting critical (e.g., danger) stimuli is to install multisensory alarms.

Sound, attention, and emotion are linked. For example, hearing an alarm keeps arousal levels high, and if not abated, the harsh tones can generate disorientation and arouse emotions such as fear and anxiety (Horowitz, 2012).* Intrusive sounds not immediately associated with danger ("false alarms") assume "negative valence," which may be manifested as anger or annoyance, which is why using complex sound in technology, for example, as a warning, can be problematic (Horowitz, 2012). The sound of angry bees or wasps is almost universally frightening, while other modulated sounds are also experienced as very unpleasant (e.g., screeching, scraping). Because the absence of sound is unusual, silence may also represent threat (Horowitz, 2012).

To improve on basic lights and chimes as warnings within aviation, Boeing developed the engine-indicating and crew-alerting system (EICAS), which displays data concerning aircraft systems and also failures. Airbus developed the electronic centralized aircraft monitor (ECAM) system, which provides the EICAS features and also displays corrective action to be taken by the pilot, as well as system limitations after the failures. ECAM uses a color-coded display to assist pilots in assessing the potential seriousness of a situation and possible corrective actions. Attention-orienting mechanisms include synthesized cockpit voiced warnings, generally using a quiet female voice, which has been shown to attract the attention of a male (pilot) faster than a loud female voice or any male voice (Ackerman, 1990).

Using multisensory stimuli to activate more than one channel of humans' multisensory system makes sense when designing emergency warning systems when rapid detection of, and response to, a threat is critical. For example, rumble strips alongside long

* The first author recalls an anxiety-generating experience of a fire alarm sounding in his hotel room for some time after the evacuation had confirmed that this was a false alarm. After being switched off, the alarm sounded again a number of times over a 10-minute period, despite two reminders to hotel reception to switch it off!

stretches of highway are designed to bring back attention rapidly to a driver who has, or who is about to, fallen asleep at the wheel. When one or more wheels of the vehicle touch the rumble strip, the driver's startle response is activated within a few hundred milliseconds via audioceptive, proprioceptive, and vestibular sensory subsystems. A range of in-vehicle attention-capturing multisensory (e.g., audiovisual, visuotactile, vibrotactile) displays and warning systems to address driver drowsiness, distraction, and overload, in which spatial correspondence and simplicity were particularly important, have been described by Spence and Ho (2008). As noted by Proulx (2010), expert operators such as airline pilots must learn to integrate multisensory information from visual, auditory, and tactile senses.

5.3.3 Memory lapses

As a constructive process, memory uses efficient but fallible mechanisms, with memory errors revealing process fragility (Buckner & Schacter, 2004). Successful retrieval of past information was consistently associated with left lateral parietal cortex regions. Seven "sins" describe memory's imperfections. Three involve different forms of forgetting or "sins of omission" (transience, absent-mindedness, blocking), one involves intrusive memories of traumatic events (persistence), and three concern distortion of past experiences or "false memories" or "sins of commission" (Buckner & Schacter, 2004), which are as follows:

1. *Misattribution*—Information assigned to wrong source or false recognition (e.g., mistaking a previously imaged event for a real one), which occurs when an object or feature is very similar to those that have been encountered.
2. *Suggestibility*—Tendency to incorporate inaccurate information from external sources, such as misleading questions, into personal recollections.
3. *Bias*—Involves distorting influences of present knowledge, beliefs, and feelings, onto recollections of previous experience (e.g., hindsight wisdom).

In retrieval and memory processing, the PFC contributes roughly in a posterior to anterior organization. The frontopolar cortex and DLPFC are active during remembering. For familiar items, medial parietal (near precuneus), left lateral parietal cortex, and left anterior PFC were active (Buckner & Schacter, 2004).

5.3.4 Cognitive biases and error management theory

The notion that the full gamut of humans' psychological processes is the product of millions of years of evolution is not new (Kingsolver, 1995) and the likely genesis of humans' cognitive biases was explored in Chapter 4 (see especially Summary Text 4.8). Adopting an evolutionary perspective to signal detection theory and judgment under uncertainty, error management theory (EMT) maintains that asymmetrical fitness costs of different error types create biased cognitions that minimize error costs (Haselton & Buss, 2000; Haselton & Galperin, 2012; Haselton & Nettle, 2006). The essence of EMT is that behavior is designed to minimize costs not errors (McKay & Efferson, 2010). While numerous laboratory studies have revealed a wide variety of circumstances under which HE may be invoked, to avoid possible artifactual effects, ecological validity requires that a more complete understanding of HE includes reference to contemporary social and evolutionarily distal contexts.

Error-making asymmetries tend to favor behaviors that optimized survival and success among ancestral human populations. For example, mistaking a harmless stimulus (e.g., a stick) for a harmful one (e.g., a snake) is a false-positive error that typically incurs no cost (apart from possible social embarrassment). However, because making the inverse error (false negative) could be fatal, this is much less likely to occur, which tends to bias perception toward survival (i.e., safety). This can result in error management biases increasing overall error rates and thereby being apparently irrational. However, an adaptive perspective might see such error asymmetries as minimizing overall fitness costs and enhancing survival likelihood (Haselton et al., 2009; Haselton & Galperin, 2012). A detailed analysis of optimum threshold effects for different costs of false-negative and false-positive behaviors under uncertainty is described in Haselton and Nettle (2006) and in Johnson, Blumstein, Fowler, and Haselton (2013).

An example of an error management bias is the auditory looming phenomenon, whereby enhanced saliency of rising tonal intensity leads listeners to systematically underestimate the arrival time of a noise source (e.g., an approaching vehicle). As such an error would promote earlier action (e.g., avoidance, fight preparation) to counter a potential threat than would a veridical perception, it would tend to be selected for as costs of preparedness in the event of a nonthreatening approaching stimulus would typically be very low (Haselton et al., 2009; Haselton & Galperin, 2012; Haselton & Nettle, 2006). It is possible that this error management bias could have been the basis for the precautionary principle in risk management (see Chapter 11). Similar asymmetrical biases have been found with respect to height, steepness, and distance judgments, which reflect the costs to an observer interacting with the object field. Haselton et al. (2009) tabulated findings from a number of studies on perception, disease agents, conflict and cooperation (e.g., responding to perceived out-group intent), and mating, which indicated that costs of false negatives were nearly always higher than false-positive costs. Thus, many judgments attributed to "HE" might reflect DM that minimizes fitness costs (Haselton et al., 2009; Haselton & Galperin, 2012). The error management bias designed to avoid the high costs of misperceiving malevolent intent in others was evident in the case described in Summary Text 4.4.

The cost asymmetry bias toward the least costly form of error can also account for the body's evolved hazard detection systems (e.g., stress or anxiety in response to nonthreatening stimuli) as well as engineered sensors (e.g., smoke alarms) being biased toward false-positive errors even if this vastly increases overall error rates (Haselton & Nettle, 2006). Complex contemporary systems introduce multiple possibilities for error generation. For example, it has been estimated that annual U.S. hospital surgical errors contribute 50,000–100,000 deaths and over one million serious injuries (Weingart, Wilson, Gibberd, & Harrison, 2000). Reducing humans' natural error tendencies may be tackled by strategies that reflect the nature of contemporary problems. For example, rather than issuing relevant data in probability format, to improve the likelihood of making correct medical diagnoses, provide doctors with data in the more readily understood frequency format (Haselton et al., 2009). Noting that approximately 7% of medication orders had errors in their prescription or administration, the UK Cabinet Office (2012) provided a redesigned prescription chart to reduce these errors. Another option might be to reinforce the social exchange heuristic, which operates to emphasize the benefits of group (e.g., dyadic) cooperation as a result of evolutionary pressure that reflected repeated benefits of such cooperation, as well as disbenefits of noncooperation, such as reputation loss (Haselton & Galperin, 2012; Haselton & Nettle, 2006).

EMT has been proposed as a basis for understanding DM across a range of domains, including medicine (e.g., whether and how to treat cancer and other diseases), public policy (e.g., expenditure on health and welfare), engineering (e.g., extent to which safety features should be incorporated within complex systems), international security (e.g., expenditure in preparedness against terrorist and "cyberterrorism" attacks), and climate change (extent of investment in mitigation and adaptation strategies), among other DM areas (Johnson et al., 2013). Sources of variation in managing error identified by Johnson et al. (2013) included (1) time (number of opportunities may rapidly decrease over time), (2) ecology (e.g., foraging vs. predation dilemmas), (3) costs (risk taking may increase or decrease if the relative costs of false negatives and false positives change), and (4) probabilities (risk taking tends to increase as the likelihood of success increases).

EMT can be extended to apply to more complex DM domains than simple individual decisions in which there are few parameters to consider. The following ways were identified by Johnson et al. (2013):

1. Individuals, groups, or wider collectives such as organizations (all examples of DM agents) may misperceive (or disagree on) the relative magnitudes of costs and benefits of different outcomes (e.g., constructing a tourist facility or other commercial venture in a world heritage area), which could lead to conflict.
2. Agents can also misperceive probabilities of different outcomes, for example, because of how data are presented, with low-likelihood events (e.g., winning a lottery) being particularly likely to be overestimated.
3. As human society becomes increasingly complex, the likelihood of mismatches between our evolved cognitive biases and criteria involved in contemporary DM also increases, which can result in poor DM, particularly on complex issues, such as climate change.
4. While it may be assumed that most cognitive biases arose in response to problems faced by individuals, the greater likelihood that multiple agents are involved in contemporaneous DM increases the probability of disagreements over means and ends.
5. When cognitive biases that evolved to address a relatively simple problem (e.g., in-group vs. out-group relations) are applied to contemporary world issues (e.g., interstate rivalry), exaggerated versions of the original adaptive mechanism could be produced, thereby generating tensions between jurisdictions. Such tensions could be further exacerbated by cultural differences (known to affect the way in which some biases are expressed) and a range of other cognitive biases in all parties involved.

Perception of control is the essence of agency bias. Agency bias, which can be extremely powerful, is often associated with religious fervor. The agency may be oneself, a deity (single or multiple), or a vague power. Religious representations that illustrate agency bias can vary from a footballer crossing himself as s/he substitutes another player, to intense ceremonies extending over days or weeks. While superstitious behavior may be a relatively harmless and even universal form of the genre, religious fanaticism in all its guises is an extreme form of agency bias. Humans' strong motivation to control their environment has led on the one hand to unprecedented degrees of actual control (even overcontrol) of their environment through science, technology, and political mechanisms. This has led to an enhanced perception that we can control even more than is empirically possible. More dangerously, on the other hand, this bias has led to the widespread perception, propagated through ideologies—mostly but not exclusively religious—that we can control all aspects of our environment. The notion of a god who is all powerful and all controlling acts as an effective mediator for these agency beliefs. This species-generated hubris maintains that if you can influence your god, then you can affect the outcome of any event. If science and education do not eventually overcome this unsubstantiated belief bias, then humans' wildly exaggerated perceptions of our degree of control over events may be destined to continue.

5.3.5 Threat detection errors

When detecting threats, errors may be either false positive (e.g., are applied to benign individuals or situations that do not actually pose a threat) or false negative, which occurs when individuals or situations that do pose a threat are not recognized as doing so (Schaller & Neuberg, 2012). While a smoke alarm may be subject to either type of error, in this case while false positives might be irritating, false negatives could result in severe harm (Schaller & Neuberg, 2012). Because of this asymmetry in outcomes, smoke alarms are configured to minimize the frequency of potentially fatal false-negative errors, with the inevitable consequence of increasing the false-positive error rate (Schaller & Neuberg, 2012). Through natural selection the same principle applies to human threat detection so that our sensory, perceptual, cognitive, and emotional systems have evolved to minimize the likelihood of whichever type of error is most likely to be costly to reproductive fitness (Schaller & Neuberg, 2012). Our psychological processes, therefore, include inbuilt cognitive biases that lead to a greater likelihood of making the least costly form of error (Haselton & Nettle, 2006), which results in a higher rate of threat detection than is warranted by objective evidence.

While its benefits for detecting danger are critical for survival on occasion, an attendant downside is that humans' sophisticated multisensory system is highly geared to detect stimuli and to make sense of any that are available, which leads to a high rate of false-positive identifications. Thus, we tend to "see" meaning or patterns in random input where none exists, which accounts for people's belief in a range of phenomena, including generalized "personality" statements typical of astrological accounts, belief in fate rather than coincidence, attributing deliberation to actions where none exists, and various supposed paranormal phenomena. Many paranormal phenomena (e.g., "ghosts") can be ascribed to multisensory hypervigilance in the face of imagined threats, perhaps reinforced by numerous literary and cinematic experiences.

5.4 From cognition to behavior

5.4.1 Situation awareness

Of cognitive factors that could reduce the likelihood of HE resulting in harm, SA has arguably garnered the most attention in contemporaneous research. As noted in Chapter 2, consciousness and associated cognitive states, including awareness, attention, learning, and memory, are at the core of humans' sensory system. SA is an extension of at least two of these concepts (awareness and attention). According to Endsley (1995a), SA comprises both the process of acquiring and the product of awareness. Offering potential explanatory value for human behavior in the face of immediate or imminent danger or possible harm, SA has gathered momentum as a research topic mainly in the cognitive ergonomics/HF literature. The literature on traumatic brain injury (TBI) has contributed by identifying various awareness deficits that result from TBI and in developing a model that posits a relationship between SA and other forms of awareness, which is outlined in Summary Text 5.4. The model outlined in Summary Text 5.4 shows how SA links with other aspects of awareness, for example, relevant memory encodings, all of which are likely to be important with respect to managing performance, including error monitoring and correction.

Developed initially for the aviation sector (Stanton, Chamber, and Piggott, 2001), SA has been adopted in several other high-hazard sectors and SA failure is frequently cited, albeit controversially, as a "causal" factor in accidents or incidents (Salmon & Stanton, 2013).

SUMMARY TEXT 5.4 A Model of Awareness Developed from Research with Brain-Injured People

Integrating concepts from cognitive psychology, social psychology, and neuropsychology, Toglia and Kirk (2000) proposed a dynamic model of awareness focusing on the interplay between knowledge, beliefs, task demands, and context. Their model was based on earlier work by Crosson et al. (1989), who proposed a 3-stage hierarchical ("awareness pyramid") model in which intellectual awareness formed the base, with emergent awareness at the mid-level and anticipatory awareness at the top. Recognizing the multidimensional nature of awareness, each stage was predicated on its predecessors. While in Crosson et al.'s (1989) model intellectual awareness referred to knowledge that some function was impaired, it could equally well apply to impairment resulting from temporary conditions (e.g., distraction, fatigue, or the effects of alcohol or other drugs). Emergent awareness referred to problem recognition, while anticipatory awareness was the ability to realize the likelihood that a problem could occur as a result of a deficit. These concepts could also be applied to temporary as well as to longer-lasting conditions. Neuropsychological components of awareness were designated as including bilateral prefrontal regions, IPL, angular gyrus, supramarginal gyrus, and anterior tips of the temporal lobes. Toglia and Kirk's (2000) critique of the hierarchical model included that it did not explain how the different levels worked together, that implicit awareness (without consciousness) was not addressed, that different levels of awareness could be observed under different conditions, and that emotion and feedback were missing elements.

In Toglia and Kirk's (2000) model, metacognition involved conscious knowledge of cognitive processes and monitoring and self-regulating current activity. Metacognitive knowledge includes declarative (factual) knowledge stored in long-term memory and a sense of mastery (beliefs about oneself). To describe the process of monitoring current performance, Toglia and Kirk's model used the term *online* or situation awareness, which incorporated Crosson et al.'s (1989) categories of emergent and anticipatory awareness. In Crosson et al.'s model, situation was one type of compensation strategy for awareness deficits, the others being anticipatory, recognition, and external. In Crosson et al.'s model, intellectual awareness (of a deficit) was required for the situational compensation strategy to be applied consistently and to be practiced many times so that it became a habit.

Toglia and Kirk's model postulated continuing interactions between stored knowledge, beliefs (e.g., self-efficacy), affective state, and SA. Gaining awareness is conceptualized as the process of restructuring self-knowledge (Toglia & Kirk, 2000). While these models were developed to assist in the prognosis and rehabilitation of brain-injured individuals, they could also be applied to awareness more generally. In Toglia and Kirk's (2000) multidimensional model, SA is activated by tasks/events and comprises appraisal of current task or situation (anticipatory awareness), task experience, self-monitoring of current state (emergent awareness), error recognition and self-regulation (performance adjustment), and self-evaluation (beliefs and perceptions about performance). Metacognitive (stored) knowledge includes tasks, strategies, procedures, self-knowledge, beliefs (intellectual/implicit awareness), self-efficacy, and affective states. Influencing factors include perceptual deficits, emotional state, fatigue, motivation, task difficulty, culture, context, and value. Responses to feedback include agreement, confusion, surprise, indifference, resistance, hostility, and anger. Such a model can help to identify some features of the psychological legacy of SA and also assist in understanding how this concept can be associated with related features of awareness, task performance, and error monitoring.

In Toglia and Kirk's (2000) model, lack of SA represents one category of six in their self-awareness deficits typology. This suggests the relative degree of importance of SA within the context of other factors affecting performance (e.g., driving). Illustrative examples from Toglia and Kirk's (2000) account are listed below. This partial list indicates that while features associated with SA are important in monitoring and regulating performance, when considering the broader tapestry of error management, there are many other potential factors to consider, most of which have been well documented in the HF literature:

1. *Self-knowledge* (e.g., cannot access required knowledge when required = memory deficit, false judgments/beliefs about one's capabilities, unable to accept deficits)
2. *Situation awareness (SA)* (e.g., performance overestimation, unfamiliar/ambiguous task demands, failure to integrate all aspects of task, lack of planning/selecting goals)
3. *Task performance* (e.g., failure to recognize errors, inaccurate feedback, lack of motivation, failure to see need for strategies to achieve goals, overfocus on irrelevant information)
4. *Problems recognized but performance not adjusted* (e.g., unable to use feedback, unable to change strategy, unable to access relevant stored knowledge, inappropriate response to error)
5. *Self-evaluation* (e.g., does not initiate self-checking of performance, false beliefs about capabilities, difficulty in reflecting on performance and connecting with outcomes)
6. *Integration failure* (does not retain the new experience over time)

SA boasts an expanding lexicon that includes distributed, team, transactional, driving, and work varieties (Salmon, Stanton, Walker, & Jenkins, 2009; Salmon, Walker, & Stanton, 2015). While being aware at one level implies that there must be some "situation" to be aware of, perhaps to draw attention to relevant environmental factors in the generation and perception of threat, this term has become attached to the notion of awareness, often when making attributions with respect to errors. Requiring both sensory input and memory for previously learned associations, as well as cognitive appraisal of potential harm, SA might be considered as the immediate dynamic perception of risk. More comprehensively, SA has been conceived of as a distributed systems phenomenon rather than as an attribute of an individual operator (Salmon et al., 2015).

As a continuing feature of human cognition during the fully awake state, which includes anticipating possible future states, SA is more broadly based than vigilance. While some SA literature comes perilously close to candidature for the hundreds of "ongoing situations" submissions from readers of the UK satirical magazine *Private Eye* during the

1980s, which were eventually discontinued, presumably on grounds of ongoing tedium, here we review current empirical evidence and theoretical underpinning for SA.

As a concept with both dispositional and state components, SA is subject to individual variation (e.g., Young, Salmon, & Cornelissen, 2013b) and to performance-influencing factors (e.g., distraction, stress, fatigue, overload). SA is goal-driven and motivated by sensemaking (Golightly, Ryan, Dadashi, Pickup, & Wilson, 2013), while SA inputs are multisensory (Chapter 2). A function of experience, training (Walker, Stanton, Kazi, Salmon, & Jenkins, 2009), and available technology (Salmon, Lenné, Young, & Walker, 2013), SA can be either enhanced or degraded by selected design features, such as in-vehicle technology or degree of complexity in collaborative systems (Salmon & Stanton, 2013).* Spatial disorientation compromises SA by confusing the senses—for example, flying a helicopter at night with no visible horizon (ATSB, 2013). Demonstrating their particular skill set, orienteers were significantly more likely to find their correct location by identifying its unique features using disconfirmatory logic, while by adopting a mainly confirmatory approach in ascertaining their location when lost in different simulated environments, pilots and students displayed a strong confirmatory bias, which in real-world circumstances might have meant that they could have faced much greater risk (Gilbey & Hill, 2012).

A key design issue is to tailor systems to maximize situation awareness (Salmon & Stanton, 2013). Generic schemata, which are templates for perception, comprehension, and action, can be distinguished from transient schemata, which instantiate a generic schema for particular circumstances (Stanton, Salmon, Walker, & Jenkins, 2009). Examples of cyclists' generic schema for different types of road configurations (intersections, arterial roads, shopping strips, etc.) were provided in Salmon, Lenné, Walker, and Filtness (2013). Different varieties of SA include broadly based (like a trait), focused (e.g., on a current task), and goal directed (Golightly et al., 2013). Communication between team members constitutes transactional SA (Sorensen & Stanton, 2013).

Described extensively elsewhere, only brief outlines are provided here of SA models. Neisser's (1976) broadly based perceptual cycle model—(1) perceived environment, (2) memory schemata, and (3) active exploration—has been used as the basis for other SA models. Smith and Hancock's (1995) cognitive generative SA model postulated an adaptive externally generated consciousness (i.e., environmental awareness embedded in memory systems via learning). Developed for the aviation sector, Endsley's (1995a) 3-level model comprised (1) perceived relevant elements, (2) situation comprehension, and (3) projected future development. Linking with HF/RM models is individual psychological schema theory (Salmon, Read, Stanton, & Lenné, 2013; Stanton et al., 2009; Walker, Stanton, & Salmon, 2011). Schömig and Metz's (2013) 3-level model consisted of planning (time frame minutes), decision (seconds), and control (milliseconds) elements. The oil drilling exploration sector context led Sneddon, Mearns, and Flin (2013) to develop a model whereby work safety awareness (WSA) mediated the influence of performance-shaping factors upon safety outcomes. Sneddon et al.'s (2013) WSA model comprised four subscales (concentration, attention, anticipation, distraction) mediating the impact of fatigue, sleep disruption, and stress, upon unsafe/safe outcomes ("near misses," accidents, unsafe behaviors). Interpreted as narrowing the attentional field by compromising working memory, stress predicted WSA, while lower WSA predicted high unsafe behavior (Sneddon et al., 2013).

* For example, having been trained to use the plane's rudder to correct for wake turbulence, the pilot of AA Flight 587 that crashed into Queens, NY, in November 2001 tore off the plane's vertical stabilizer (tail) by inappropriate rudder use, which among other changes led to revisions in American Airline's pilot training.

SA methods may be divided into subjective post hoc measures (mainly self-completion questionnaires), behavior sampling during task performance (online or offline; naturalistic or experimental), and analytic techniques (e.g., of selective and divided attention). Ethnographic (e.g., interviewing) and other qualitative techniques have also been used, while physiological measures have been correlated with SA measures. Original and derivative sources provide further details. In addition to standard multivariate statistical techniques, analytic techniques for studying SA have included network analysis, involving measures of density, diameter, and centrality (salience or status) (e.g., Salmon, Lenné, Young, et al., 2013; Walker, Stanton, & Chowdhury, 2013), scenario analysis, and function analysis (e.g., Golightly et al., 2013). Summary Text 5.5 summarizes some SA measures.

Situation awareness as been used to enhance understanding of how different road user groups variously interpret traffic environments, revealed, for example, by substantial

---

SUMMARY TEXT 5.5 Some Situation Awareness Measures

Some questionnaire methods have been based upon "cognitive failure" scales, including the Cognitive Failures Questionnaire (Broadbent, Cooper, Fitzgerald, & Parkes, 1982), the Short Inventory of Minor Lapses (Reason & Lucas, 1984), and the Workplace Cognitive Failures Scale (Wallace & Chen, 2005). Subjective SA measures include the following:

- SA Rating Technique (Taylor, 1990)
- SA Global Assessment Technique (Endsley, 1995b)
- Mindfulness Attention Awareness Scale (Brown & Ryan, 2003)
- Factors Affecting SA (Banbury, Dudfield, Hoerman, & Soll, 2007)
- Workload, Error, SA, Time and Teamwork Analysis (Houghton, Baber, Cowton, Stanton, & Walker, 2008)
- Work SA Scale (Sneddon et al., 2013)

Probe techniques have included the following:

- Critical Decision Method (Klein, Calderwood, & MacGregor, 1989)
- Situation Presence Assessment Method (Durso & Dattel, 2004; Durso et al., 1995)
- Experimental/Naturalistic Online Probes (e.g., Bacon et al., 2011; Bacon & Strybel, 2013)
- Verbal Protocol Analysis in Naturalistic Driving (e.g., Salmon, Lenné, Young, et al., 2013; Walker et al., 2013) or Cycling (Salmon, Lenné, Walker, et al., 2013)
- Verbal Protocol Analysis Plus Instrumented Vehicle Data in Naturalistic Driving (Salmon, Young, et al., 2013)

Other online probe techniques have been described by Strybel et al. (2011). Whether SA is sufficiently mature for the theoretical and methodological consensus called for by Salmon and Stanton (2013) is a moot point. Benefits of exploring a concept using a variety of techniques might generate a more robust and useful long-term concept.

---

differences in SA concepts verbalized by road users. Thus, Salmon, Young, and Cornelissen (2013) found that on a mixed route, compared with that of cyclists and motorcyclists, drivers' SA made more connections between environmental features. This might result from road systems being designed essentially for motor vehicle users, thereby providing a more interconnected overall environment for this group. However, in some route sections (e.g., a shopping strip), motorcyclists' SA was more interconnected than those of other road users studied. Problems encountered by cyclists in navigating environments designed for motorized vehicles were highlighted by their use of more constructs but with lower connectedness than for motorized road users, suggesting lower overall SA integration (Salmon, Young et al., 2013). However, there is no a priori reason to suppose that a well-integrated SA is any "better" than a disconnected one, as each road user group selects the SA schema most appropriate for its safety. For example, cyclists' focus on hazards and alternative routes reflected their particular threat awareness, leading Salmon, Lenné, Walker et al. (2013) to identify threat assessment as an important part of cyclists' SA. The anticipatory component of SA was best represented by motorcyclists, reflecting a relatively greater degree of hazard created by the road environment for this group.

To reflect their potential differential effect, Underwood, Ngai, and Underwood (2013) distinguished between abrupt-onset hazards, requiring attention capture and fast reaction time to successfully avoid, and gradual-onset hazards, requiring anticipation to navigate. These authors' finding that experienced and inexperienced drivers detected both types of hazard equally well might suggest a universal innate hazard detection system. However, motorcycle rider/drivers were designated as having "higher SA" generally, even in relatively "safe" roadway sections, and also detected gradual-onset hazards faster than car drivers did (Underwood et al., 2013). Motorcyclists' greater vulnerability could explain this finding. Although abrupt-onset hazards may initially activate the preattentive neural network (e.g., startle, orient, defense), while gradual-onset hazards require both sensory input and top-down cognitive interpretation, both require effective planned avoidance actions. While an application of such studies is that road user training could usefully focus on anticipatory aspects of gradual-onset hazard detection, the extent to which the SA concept is required to appreciate this is moot.

The relevance of road design to SA was illustrated by Walker et al. (2013), who identified a self-explanatory hierarchy of road types, with highways representing the highest level of explanation and progressive reductions represented by increasingly minor roads. This might imply that driver/rider transitions between road types could be critical, as the degree of explanation for "ideal" behavior (e.g., speed restrictions) could change at each transition. However, the concept of *affordances* might provide an equally appropriate explanation for road user responses to different road types.

Other influences on driver performance include distraction and workload, both of which have been studied experimentally and in naturalistic settings. In a meta-analysis, Young and Salmon (2012) identified distraction and driver error as being highly related and estimated as contributing to the etiology of 75%–95% of vehicle crashes, with secondary distractions contributing to 23% of crashes. Secondary distractions include listening to music, which has also been associated with driver errors, violations, and aggressive driving (Brodsky & Slor, 2013). Young, Salmon, and Cornelissen (2013a) found that while the (18) types of errors (e.g., speeding, lane excursion) made by distracted and undistracted drivers did not differ, while there were error type differences, distracted drivers made significantly more errors overall (48% higher likelihood). These authors also found that while distraction did not affect the structure of drivers' SA, increased load changed SA content, narrowing drivers' focus from visual scanning to vehicle control tasks (Young et al., 2013b). This outcome was consistent with that of Schömig and Metz (2013) who found that drivers could compensate for increased workload by deciding what to focus on, with long-term memory guiding attention to relevant cues (Chapter 2). The relevance of SA as an explanatory concept in these studies is again problematic.

Reflecting findings that while expert drivers scan the roadway widely, novice drivers focus on the road ahead (Underwood, 2013), Salmon, Lenné, Young et al. (2013) found that novice drivers tended to focus on SA concepts related to their own performance rather than to other road users. Compared with novices, experienced drivers had fewer SA concepts, but they were more interconnected, with SA being more implicit for experienced drivers, who did not need to extract as much information from a given situation. Experienced drivers' more highly developed schemata resulted from learning and memory for the range of previously sampled situations (Salmon, Lenné, Young, 2013). Examining the accident at Kerang (Australia),* Salmon, Read et al. (2013) combined individual psychological schema theory with systems factors to identify contributory error types. Acknowledging inadequate schema development as a contributing factor, the authors urged moving away from individual blaming to a systems learning approach. While the truck driver was acquitted, the subsequently upgraded Kerang crossing design included boom gate installation, enhanced warnings, and a lower approach speed limit. This case illustrates how the SA concept can be used to make design improvements to increase the likelihood that system users will be more aware of the potential for harm.

Golightly et al. (2013) described an example of a team approach to SA (distributed SA), in this case rail track work, in which the lookout acts as a human sensor. To be effective this role requires special skills. In an experimental study based upon traditional 5-person group configurations, Sorensen and Stanton (2013) found task success and distributed SA to be positively correlated. For their particular task, the "Y" formation, in which peripheral group members passed information through an intermediary to the central control function member, was the most successful.

SA has been used extensively to explain certain behaviors in relation to incidents. For example, failure to detect warnings by vehicle drivers involved in rail-level crossing accidents has been attributed to "poor SA" (Salmon, Lenné, Young, et al., 2013), or in the case of a particular accident, to "diminished SA" (Salmon, Read, et al., 2013). Reviewing crash investigation literature, Bacon and Strybel (2013) revealed that large proportions of aviation incidents were attributed to "SA failures," "inadequate SA," or "SA problems." Does "lack of SA" equate to "error?" Like error attributions, "SA failure" offers little in the way of interpretation, being symptomatic of underlying events or strategy. Dekker's (2013) critique of the widespread application of SA to attributing blame to people involved in incidents, particularly in transport, through "loss of SA" revisits hindsight bias (Hidden, 1989), by suggesting that information that was available, and which could theoretically have been accessed, therefore should have been. The role of SA concepts in generating improved design (controls, displays, etc.) that improve safety and reliability is quite distinct from employing SA concepts to make retrospective judgments about operators' performance. Dekker (2013) claimed that legitimization of the SA construct in HF research has led to a focus on (incident) situations while ignoring or downplaying the role of consciousness or sensemaking.

* The circumstances here were similar to the 1968 Hixon (Great Britain, Ministry of Transport, 1968) level crossing accident in which a similar number of train passengers were killed when a low-loader road vehicle was grounded on a level crossing before being struck by the train.

In deconstructing Dekker's (2013, 2015) critique of SA, it is important to distinguish between SA as a research tool, for example, as a basis for analyzing performance in various contexts, and identifying SA as an alleged component of incident (crash, accident, disaster, etc.) etiology. The issue might more usefully be expressed not as one of "causality," which is inevitably problematic, but whether SA has any explanatory power in incident etiology. SA may be useful to assist in understanding how humans make sense of their environment, particularly in the face of complexity. However, that is quite different from using SA as an explanatory component of incidents. One problem in using SA failure as a "cause" is that, as the vast majority of errors do not lead to incidents, nearly all instances of "loss of SA" do not lead to undesired outcomes, but like errors can usefully serve as learning opportunities, certainly for individuals and ideally also for organizations and systems. Extrapolation to incident etiology is invalid because it assumes that a construct developed by researchers to assist contemporaneous exploration of aspects of human sensation, perception, and conscious awareness can be used retrospectively (i.e., with the benefit of hindsight) to make judgments about what an operator(s) could or "should" have perceived. These two applications of SA—(1) as research concept and (2) as an incident investigation tool (e.g., Salmon, Read, et al., 2013)—need to be recognized as distinct and not be confused. Understanding current performance is not equivalent to judging past behavior. Perhaps the most useful application of SA in incident investigation is to help highlight system elements that need to be changed to obviate reliance on the accuracy of human perception on every encounter with a hazard—for example, leading to useful training programs (e.g., Stanton, Walker, Young, Kazi, & Salmon, 2007) or road design changes (e.g., Salmon, Lenné, Walker, et al., 2013). In this way, SA can potentially offer useful guidance for HF safety-enhancing applications (e.g., Salmon, Read, et al., 2013).

One reaction of SA researchers to (potential) criticism has been to generate ever-finer-grained quantitative and qualitative analyses to identify SA dimensions. Challenges for SA researchers include moving beyond stating matters that are intuitively evident and differentiating SA from related concepts (e.g., attention, perception, vigilance, or merely "awareness"). The latter challenge requires theoretically guided empirical research to demonstrate SA's unique conceptual utility. SA research has the potential to progress beyond stating that different (e.g., road) environments represent different levels of risk and are represented differentially cognitively. However, maintaining that SA *explains* how drivers use information to combine long-term with short-term goals (Walker et al., 2013) requires much more robust conceptual development to show how SA can demonstrate explanatory power over and above other available constructs. A further challenge is to eschew implied explanatory power of SA in incident investigations.

Empirical research using the SA construct, for example, leading to evaluated interventions, has been initiated. SA researchers are beginning to identify qualitative and quantitative differences in cognitions, for example, for various road user groups in different environments. It remains debatable whether the SA concept will be best consolidated and advanced through intuitively obvious findings, or whether counterintuitive findings are required to reveal theoretically useful discoveries. Further progress might be made by determining what neural architecture is involved in representing different environments and how neural mechanisms represent environmental transitions.

5.4.2 Beyond immediate safety considerations

Hitherto, SA has been applied exclusively to situations involving imminent risk or potential for harm with typical timescales ranging from milliseconds to a few minutes, relating to immediate safety but not to long-term health issues. As currently conceived, SA is thereby limited in scope. While incidents that could result in death or trauma to individuals or collectivities (e.g., airplane passengers) should obviously be avoided by all reasonable means, including through enhanced understanding of how SA impacts skilled performance, the great majority of deaths (~80%) occur not from trauma but from disease, ill health, or age-related degradation from a variety of vectors. While death is inevitable for everyone at some point, the goal of maintaining a healthy life for as long as possible is a prime motivator for many people.

To align with the facts of how most people die, an extended SA construct is required, which might be called *condition awareness* (CA), perhaps as a component of self-awareness. Again with both dispositional and state aspects, CA reflects an individual's understanding and cognitive–emotional representation of their current and projected state of health and the behaviors that ideally would be engaged in to achieve optimum health outcomes (e.g., best possible health for longest possible duration). Analogous with Endsley's (1995a) SA model, but operating at different timescales, a CA framework might involve three levels: (1) sensation, inputs from internal (own body) and external environments; (2) perception, integrating and understanding these inputs, including risk communications; and (3) action, behaviors designed to deliver optimum long-term outcomes. These levels are variously represented in social-cognitive health behavior models (e.g., EPPM, HAPA, HBM, PMT, TPB/TRA). All three levels operate more or less continuously throughout life in constant feedback to represent CA. Figure 5.1 outlines a simple representation of CA operation.

CA refers to awareness by an individual of their internal health (mental and physical) and major external factors affecting it. CA is subject to individual differences in the ability to understand educational and informational inputs and degree of agency to act upon them (cf. social-cognitive health behavior models). The inevitable lag between scientific discoveries and their translation into general educational communication can be mitigated by rapid availability of health information via contemporary media channels. High-CA individuals actively seek information, both from their own bodies, including changes over time, and from their environment—from experts and other sources that might provide useful information. They carefully interpret and organize all available information to continually update action plans. Within constraints that might be imposed, they engage in behaviors designed to prolong healthy life (e.g., diet, fitness regimes) and minimize or do not engage in behaviors that might either shorten or reduce their quality of life (e.g., drug-taking,

Level	Typical features
Sensation	Awareness of messages from own body and environmental influences drives conscious search for health- and safety-relevant information
Preception (cognition)	Understanding (cognitive and emotional) the importance of health-related information; multiple information sources integrated into memory to generate intended action programs
Action	Implementation of intended behaviors resulting from sensations and perceptions, modified by available degree of agency (e.g., personal resources available, barriers to action)

Figure 5.1 Simplified three-level framework for (health and safety) condition awareness.

dangerous leisure pursuits). In that safety is a special case of health, within this framework SA is a specific case of CA that relates to rapidly developing conditions. As a special case of CA, SA asks the question: "How does my current situation (regarding criteria of safety, risk, and potential harm) affect my long-term health condition?"

5.5 Errors as a crucial learning mechanism

It is axiomatic that a critical feature of human learning involves experiencing performance error, either directly or vicariously. While for an individual, a performance error might prove fatal (e.g., driving while texting), for a community, or an organization, or some other wider grouping, it could provide a valuable learning opportunity. Thus, for collective safety to improve, individuals may occasionally be "sacrificed," for example, to raise error awareness within the collective. Fortunately, most errors can also lead to individual learning and may be considered as stages on the route to enhanced learning. In terms of the concepts described in Chapter 2, error recovery is central to human consciousness, attention, awareness, and memory, as well as learning. Therefore, what is typically presented as the "HE problem" may more appropriately be identified as critical in motivating the search for designing and developing safer equipment and systems.

Two transport sector examples reveal how performance errors have driven the development of safer systems. Over its 150+-year history, rail safety has progressed partly through learning from successive inquiries into rail incidents and disasters, often involving multiple fatalities, to produce arguably the safest form of mass transport yet developed. Major incidents that continue to occur in this sector often reflect that both technological and human operational capacities are driven to produce ever-tighter reliability and performance schedules.

A similar set of principles has benefitted the much younger civil aviation sector, which is almost unique in being regulated internationally. Although it shares this form of regulation with the maritime sector, aviation's level of international regulation is much tighter and recognized by jurisdictions globally. While each major jurisdiction has its own investigative civil aviation authority (Australian Transport Safety Bureau, National Transport Safety Bureau, etc.), the International Civil Aviation Organization requires sharing and widespread distribution of civil aviation crash investigation inquiry report findings so that valuable information is widely distributed. Many air crash investigation findings have involved HF issues, leading to enhanced safety features within this sector (Glendon, 2011b).

5.6 Some error-reducing strategies

Rather than provide a comprehensive overview of HF and other strategies to minimize effects of HE on task performance, which is featured in the second edition of this book, this section describes a few selected current topics, with a focus on transport and healthcare sectors.

5.6.1 Increasing system automation

A fundamental tenet of ergonomic/HF practice, allocation of function between human and technological agencies, is as applicable to contemporary task performance as when it was first conceived. As a way of reducing the possibility of HE ending in disaster, automation of most features of aircraft operation has been increasing almost since the start of aviation. While some evidence indicates that pilots are the last line of defense when automation fails, over-reliance on automated systems has allegedly reduced pilots' SA, particularly in some critical incidents (FAA, 2013; Li & Greaves, 2014). While cockpit automation has improved aircraft safety, there have been concerns about the role of automation in a number of aircraft incidents. General concerns about automation include the following (FAA, 2013; Pizziol, Tessier, & Dehais, 2014):

- Loss of pilots' manual skills
- Pilot out of the loop in automated operational settings
- Replacement of pilots' trained recognition abilities with less proficient sensors
- High false alarm rates that may reduce attention to possible system malfunction
- Increased pilot monitoring load with associated attentional lapses
- High responsibility with relatively low workload during long flights
- Displays that do not support optimal pilot performance
- Unexpected autopilot function
- Managing malfunctions for which procedures/checklists are unavailable/incomplete
- Lack of system feedback through displays/alarms
- Misdiagnosis of automation problems, leading to inappropriate "solutions"
- Unseen/hidden transitions between system states
- Displays that do not allow for inter- or intraindividual variance in vigilance levels
- Failure to recognize some vigilance issues until after incidents have occurred

Automation commission errors can arise when pilots terminate situation assessments prematurely, while pilots may be unprepared to take control when automated systems malfunction. Over-reliance on automation ("automation bias") and unexpected actions taken by automated systems ("automation surprise"), which can degrade pilots' SA, have been among identified potential error-inducing circumstances (Li & Greaves, 2014; Pizziol et al., 2014). Accident analyses have identified three suboptimal flight crew–automation interactions (Pizziol et al., 2014):

1. Automated behavior—Autopilot state changes independently of pilot action
2. Operator authority limits—Pilot action fails to alter autopilot state
3. Unintended side effects—Pilot action leads to a cascade of autopilot state changes

Testing three flight simulator conflict scenarios on ten experienced pilots, Pizziol et al. (2014) found that the first conflict (aircraft climbed instead of leveling off as required) was unnoticed by 8/10 pilots and could have led to a collision with another aircraft. While the second conflict (brief overspeed resulting in autopilot disconnect) was noticed by all participants, three did not handle the situation appropriately. The third conflict (autopilot reversed following speed alteration to just under maximum cruise speed so that selected target altitude could not be reached with positive vertical speed and plane leveled off instead of descending) was also noticed by all participants but provoked typical automation surprise, with only one pilot claiming to have understood the automated system changed. While simulated scenarios might generate training improvements by enhancing understanding of the pilot–automation interface as well as indicating scope for system design changes, the variety of automated systems in different aircraft might indicate a more generic approach of increasing understanding through better interface system state indicators for feedback and alerting (Pizziol et al., 2014). In a review of flight path management systems, the Federal Aviation Administration (2013) detailed 18 recommendations for reducing aircraft vulnerability and improving flight safety and operational effectiveness.

Adopting a systems approach to railway intelligent infrastructure, Dadashi, Wilson, Golightly, and Sharples (2014) identified data, knowledge, and intelligence levels of operating. These three levels were the basis for developing HF requirements and implementing automated systems for job design, teamworking, communications, and DM support. A key principle of an HF approach to automation is to ensure that as far as possible this is human-centered or adaptive automation (Dadashi et al., 2014). While not developed primarily to reduce errors, railway intelligent infrastructure was designed to replace a "find-and-fix" solution to problems (e.g., system faults) with a "predict-and-prevent" approach, including error detection and mitigation.

While study of automated systems affecting road vehicle operation has questioned whether automated driver-assist systems fundamentally change driver workload (Banks, Stanton, & Harvey, 2014a, 2014b), they can introduce additional complexity (Banks et al., 2014a). As in aviation and other systems, the effectiveness of driver-assisted automation has been questioned from the perspective of reducing the driver's SA. More stringent testing of new road vehicle automated systems is, therefore, being adopted (Banks et al., 2014b). From simulated driving data, these authors analyzed drivers' responses to emergency situations with the critical decision method using cue, generalization, basis, options, and time pressure probes. Data from both concurrent and retrospective verbal protocols were coded. The adaptive application sequence of control elements was monitor → threat recognition → anticipate movement → determine strategy → respond if necessary (Banks et al., 2014b).

5.6.2 Intersector knowledge transfers

Simulation of some relatively standard operational tasks (aircraft, military vehicles, road vehicles, trains, control room operations, etc.) has been in use for many years. As virtual reality (VR) technology continues to improve, there is the potential for further expanding this methodology to include applications in health care, numerous industrial settings, and financial markets. Multisensory (visual, auditory, kinesthetic, etc.) possibilities for VR simulation feedback continue to expand. An example from the health-care sector, described by Cameron et al. (2011), involved a haptic glove based on electroactive polymers, which generated light touch and vibratory sensation to the fingertips to improve surgical performance and reduce error likelihood. This technology allowed medical professionals to practice high-risk procedures in a low-risk VR environment (Cameron et al., 2011). The haptic glove allowed for accurate position sensing, tactile feedback, and hand representation within a training setting. For user acceptance, requirements for the haptic glove included being ultralightweight, having accurate tactile representation, portable, easily integrated into other simulations, ergonomically sound, and not impeding normal actions (Cameron et al., 2011). Parallel design principles could be incorporated into a range of potential VR applications in various sectors.

Simulation is one among a number of examples of how HF developments in training or design can be transferred from aviation, the military, and other sectors to health care. Using a dynamic safety model framework, Catchpole (2013a, 2013b) sought to enhance understanding of the relationship between systems design and human performance within health care systems. While rules and procedures may represent fragile safety barriers, violations might reflect good intentions to complete tasks effectively, even if the behaviors thereby generated may be unsafe. The technology acceptance model illustrates how violations and compliance might be modeled, for example, by operationalizing organizational pressures, social norms, teamwork, professional standards, attitudes, prior knowledge and experience, and evidence bases (Catchpole, 2013a). Five types of violations were described by Catchpole (2013a):

1. *Erroneous*—Due to lack of understanding or experience
2. *Exceptional*—When unusual circumstances may require a novel response
3. *Situation*—When the environment makes compliance difficult
4. *Routine*—Regularly taken shortcuts
5. *Optimizing*—Generated by a desire to improve work practices

Adopting a systems approach to performance improvement rather than relying on seeking only behavioral changes led Catchpole (2013b) to identify the translation of crew resource management (CRM), developed in aviation, to health care environments, where in addition to reduced error rates, CRM has resulted in improvements to team skills, teamwork, processes, perceptions, patient satisfaction, briefing compliance, and sustained organizational change. However, translating these and other advances in aviation into health care environments requires appreciating differences in the ways in which various aspects of the two system types operate. Contrasting aviation and health care system features described by Catchpole (2013b) were equipment design, task design, communications and teamwork, selection and training, and incident reporting systems.

5.6.3 Other approaches

In allocating resources to reduce error, a range of agencies have developed a variety of strategies that incorporate error reduction either implicitly or explicitly. For example, in providing a host of standards offering global guidance across multiple sectors, the International Organization for Standardization produces documents such as ISO (2013), which provides guidance on developing systems that suit the needs of diverse users. National governments produce reports that provide information on behavior change, such as the Behavioural Insights Team based in the UK's Cabinet Office (2012), which, drawing on research in the behavioral sciences, offered guidance on designing strategies to reduce fraud, error, and debt. Motivation for publishing such reports included an estimate of the national annual amount lost to error at £9.6 billion (Cabinet Office, 2012). The principles adopted by this team were outlined in Summary Text 4.7.

Observing 21 handoff events sourced from NASA, two nuclear power generation plants, a railroad center, and an ambulance depot, Patterson, Roth, Woods, Chow, and Gomes (2004) identified critical handoff features when high consequences of failure existed. Noting the variety of strategies required in the different organizational settings, the authors identified the health care environment as the most problematic for risk factors (to patients). Recommendations included using personalized technology (e.g., PDAs) for nurses and automated logs to supplement, but not replace, face-to-face communication (Patterson et al., 2004). Informed by a series of medical cases, Patterson, Woods, Cook, and Render (2007) confirmed that while cross-checking could enhance system resilience, neither routinized cross-checks nor personnel without required specialized knowledge, nor automated software, could ever detect all errors. These authors advocated using personnel with weakly defined roles who were not hindered by production pressures as having a useful contribution to make to collaborative cross-checking (Patterson et al., 2007).

Biases and dispositions as potential error-generating features of human cognition may lead to adverse outcomes when diagnosing patient conditions, which could be critical for patient care, even when such biases are known about by the potential perpetrators.

While a series of medical case vignettes presented to doctors generated an incorrect diagnosis rate of 30%, when each included a single piece of misleading information, the resultant incorrect misdiagnosis rate rose to 90%, which was not improved even when the doctors were warned about the inclusion of possible misleading information (Arzy, Brezis, Khoury, Simon, & Ben-Hur, 2009). Further requiring the participants to reassess their diagnosis using specified criteria reduced the error rate to 50%, leading the authors to recommend systematic reexamination and verification of leading diagnostic clues to reduce diagnostic error rates (Arzy et al., 2009).

While some organizations can tolerate high error rates for active learning to occur, high-reliability organizations (HOs) cannot. Using a health care environment as representative of HROs to explore the dilemma between the requirement for active learning in novice professionals and minimizing the error rate in patient care, Katz-Navon, Naveh, and Stern (2009) noted that HROs needed to balance active learning with safety priority and managerial practices. These authors found that too high a priority on safety could have a detrimental effect on treatment errors. However, a high active learning climate combined with an intermediate level of safety priority was associated with a relatively low frequency of treatment errors. Distinguishing management safety practices and priority of safety as separate features of safety climate/culture (see Chapters 8 and 10 for further discussion of this topic), a generic message in reducing error rates was highlighting the importance of safety management within the line manager's role (Katz-Navon et al., 2009).

The increasing complexities of battlefields as well as routine operational tasks have prompted armed forces to reflect upon effects of error upon a variety of military activities. For example, the Royal Navy (Bridger, Pisula, & Bennett, 2012) produced *A guide to understanding human factors and human behaviour in safety management and accident investigation*. After outlining a few standard models of accident causation, the report defined error types, emphasizing violations, using a typology almost identical to the one described in Section 5.6.2. A series of flow charts, diagrams, and simply stated principles for influencing behavior were illustrated by descriptions of a number of maritime accidents. Inclusion of some discussion points suggested that the document might be used as the basis for training. To reduce confusion in the identification of military vehicles, which could lead to friendly fire incidents, Bohil, Higgins, and Keebler (2014) developed card-sort and similarity-matching tasks that enabled prediction of 45% and 84%, respectively, of military vehicle confusions. The authors recommended using versions of their experimental tasks to create personalized automated adaptive training programs to improve the accuracy of military vehicle identification.

While government and military agencies publish reports and develop training programs, for much of the populace, an increasing source of information about improving their lives by reducing error and enhancing their well-being will be through personalized technology, particularly smartphone apps. Finding that only a small proportion of health and well-being apps continued to be used in the long term, Duddington and Seager (2013) identified several HF failures in their user survey. The authors' list of user-centered design features focused on transferring as much control as possible to the end user, including personalization, user guidance, gamification, trust, security, and anonymity, stressing the importance of providing support, reassurance, and motivation (Duddington & Seager, 2013). A broader issue concerns where responsibility for any individual citizen's health and well-being lies. The answer is responsibility shared between the individual's day-to-day and long-term care of their own health and well-being, while government and large private agencies cover emergency care when required, as well as population-level strategies such as screening, vaccination, and sanitation regimes.

A final example described by Furniss, Gould, and Iacovides (2013), established in 2009 and shared through a social networking website, is Errordiary, in which individuals can share their error and resilience experiences as well as their more generic observations and error-reduction strategies through Twitter posts or direct to the website. The aim of Errordiary is to raise awareness about the ubiquity of HE and to encourage debate, particularly about the normality of error in safety-critical domains, with a potential for generating training initiatives. Errordiary focuses on errors in health care systems and one intention is to analyze the data collected to suggest solutions to a range of identified problems. Somewhat reminiscent of Reason's (1976) initial foray into the field of HE, it remains to be determined how successful this approach will be and whether it can add anything substantial to existing models or strategies for addressing error.

5.7 Conclusions

Much conceptual thinking about safety and risk issues continues to be driven by system-based approaches. Multiple etiologies dominate explanatory paradigms for most health and safety issues. Complexity is everywhere and increasing, with implications such as "drift into failure" (Dekker, 2011). A major advance, both theoretically and practically, would be to dispense with the term human error as any sort of complete explanation for undesired incidents. A key consideration is that once this extremely low explanatory value label has been assigned, the search for wider, deeper, or more thorough explanations is abandoned. Among other implications is that the potential to learn from disasters may be compromised and attenuated. Like "SA," to avoid rhetorical circularity, more insightful diagnostics require these terms to be carefully unpacked to identify systemic and environmental factors that generated the conditions.

Thus, while HE is axiomatic, conceptually it is rarely useful or helpful in explaining incidents. Particularly within the context of complex systems (e.g., civil aviation and other mass transport), by itself "HE" is not a useful conceptual tool for understanding how complexity produces rare disasters. System-based disasters (e.g., involving multiple fatalities) result from complex combinations of factors that could not previously have been (or were not) foreseen as coming together to produce that particular disaster. Systems, especially complex systems, can effectively create HE by adding ever-greater complexity and features, thereby creating situations such that eventually an HE will not be recovered and become part of a disaster event. For example, ATC personnel or flight crew stretched to their cognitive limits by elevated contingent demands may be further hampered by impaired line-of-sight and nonoperational equipment. At that point the unfortunate operator at the sharp end, if not already part if the fatality count, is likely to be removed (or volunteer exit), while other system elements identified as contributing to the disaster may be changed or upgraded.

Both SA and HE can become part of systems' and organizations' learning to become safer when relevant data are disaggregated to discriminate between various error types (Reason, 1990) and different awareness shortfalls and how these might be addressed by system design changes. While disasters result from complexity in systems that are designed and operated by humans, they are not completely controlled by humans. Complexity generates its own disaster menu, while systems are improved by disaster experiences. Within complex systems, progress in safety is mainly incremental. It is the province of system designers to ensure that when HEs occur, they do not lead to disaster. The numerous ways of achieving this include checks, warnings, and recovery options. "Near miss" (i.e., near hit) data, which may/may not be reported and acted upon, are a potentially valuable warning mechanism.

At the heart of many risk debates is the issue of who is responsible for the safety of individuals, families, communities, organizations, and nations. A onetime interest of the first author (e.g., Glendon, 1979, 1980, 1981), responsibility for safety is inevitably shared whichever perspective is adopted—legal, moral, technical, and so on. Safety initiatives, policies, rules, and regulations represent attempts to identify parties responsible and perhaps to allocate resources that may/may not be commensurate with parties' assigned responsibilities. Resource allocations may rather reflect the political nature of many, if not most, risk and safety debates.

Neuroimaging studies have revealed a great deal about the operation of HE monitoring, detection, and correction processes, adding to preexisting knowledge of cognitive deliberations involved in managing error. Evolutionary insights have begun to direct attention away from identifying "HE" as a problem to be solved to a feature of human functioning essential to learning and as reflecting the way in which errors have been functional within the context of our historical legacy. However, the complexity of systems and organizational forms comprising our contemporary world has delivered a hitherto unprecedented series of challenges to humans' error detection processing. It is to analyzing some of these organizational and system complexity challenges that the remaining chapters of this book are devoted.

chapter six

Surviving stress

Why should safety and risk scientist practitioners be concerned with psychological stress, which presents a mental hazard, in addition to physical (e.g., visible hazards) and physiological (e.g., long-term damage) risks? First, psychological stress is an important component of health, safety, and welfare and so there is at least an ethical requirement to safeguard this aspect of employees' well-being. A second reason is that beyond a certain point, individuals under stress perform less than optimally and stress can, therefore, adversely affect productivity, quality and, ultimately, safety. The World Health Organization (WHO) has estimated that occupational stress costs approximately 3%–4% of GNP across the EU (WHO, 2008).

Research evidence supports causal links between stressful working conditions and injury involvement in various contexts, including company car drivers (Cartwright, Cooper, & Barron, 1996), transit operators (Greiner, Krause, Ragland, & Fisher, 1998), medical practitioners (Kirkcaldy, Trimpop, & Cooper, 1997), construction employees (Siu, Phillips, & Leung, 2004), and veterinary surgeons (Trimpop, Kirkcaldy, Athanasou, & Cooper, 2000). As a significant amount of work-related stress results from organizational culture and relationships, stress is a problem for organizations, not just for individuals. Stress and its management or control is widely recognized as a workplace problem. Cox and Griffiths (1996) argued that organizations should assess the risk posed by psychosocial hazards as well as from physical hazards, that is, those aspects of work design, and the organization and management of work, and their social and organizational contexts with the potential for producing psychological or physical harm (Cox et al., 1993, 1995). Dollard and colleagues argued that psychosocial risks originate at an organizational level, in relation to management practices and values, production methods, budgets, and resource allocation (Dollard, 2012; Dollard & Bakker, 2010; Dollard & Karasek, 2010). Although much legislation governing health and safety requires risks of the effect of physical hazards on health and safety outcomes to be assessed, attention has also focused on assessing the risk of psychosocial hazards on health outcomes (Cox et al., 1995; Cox & Griffiths, 1996). While the European Framework Directive on Health and Safety at Work (1989) emphasized the employer's duty to ensure the safety and health of employees in every aspect of their work, few European countries have special legislation relating to psychosocial hazards.

Stress is multidimensional and complex, having both objective (e.g., physiological measures) and subjective (e.g., cognitive appraisal) components. A definition incorporating both these components was proposed by McGrath (1976), who conceptualized stress as a sequence of events, in which a perceived imbalance occurred between demand and response capability, where consequences of not meeting demands were perceived as important. Psychological stress is experienced as an individual phenomenon and has links with motivation and personality. However, many of the origins of stress are generally held to lie externally, although the issue is not clear-cut because stress is experienced as a result of interactions between individual variables (e.g., personality, coping style, attitudes, expectations) and environmental factors (e.g., organizational culture, rate of change).

This chapter considers a topic of widespread concern to many people, that of stress and how to deal with it effectively. After reviewing the stress process and ways of conceptualizing stress, a number of workplace stressors are considered, specifically in relation to work injuries. The focus then shifts to individual and organizational level intervention strategies. The following sections describe the nature of occupational stress, before continuing to examine implications of workplace stress for health and safety management. While stress has been studied in a wide variety of contexts (e.g., in response to climate change; Bradley, Reser, Glendon, & Ellul, 2014), we focus on research within organizational contexts. Post-traumatic stress disorder (PTSD) is not covered in this chapter (for a review of PTSD, see Bisson et al., 2007).

6.1 Nature and effects of stress

A distinction has been drawn between *eustress*, which is associated with positive arousal and motivation, and distress, which may be accompanied by feelings of extreme anxiety, depression, or low self-esteem. Although sources of pressure are necessary to motivate individuals to strive toward goals and may be perceived as a positive challenge, extreme pressure, where an individual has difficulty coping, is likely to result in negative outcomes. Given the implications for maintaining the health and safety of individuals (and organizations), we use the term *stress* to refer to the latter.

Numerous models have been proposed to describe the stress process. Stress may be identified with external pressures; following the basic engineering analogy, that when stress is applied strain results. This model ignores individual differences with respect to stress reactions—for example, what one person perceives as stress, another may consider to be a challenge. Another conceptualization locates stress as a response within the individual, so that stress is a set of experiences. Stress operates upon many physiological aspects of bodily functioning. When confronted with a perceived threat, the hypothalamus and pituitary glands release a hormone (ACTH) into the blood. When ACTH reaches the adrenal glands, adrenalin and related hormones are also released into the blood and flow to all organs, muscles, and cells of the body, producing the activation (flight or fight) response. This response results in a number of neural and bodily changes, outlined in Summary Text 6.1, which are designed to prepare the individual to meet the threat.

The human flight or fight (FoF) response evolved to meet environmental threats that required an immediate response (e.g., natural hazards, wild animals, hostile members of other groups) and thus the behavioral reaction usually occurred straight away. As the rate of social change in human society has outstripped our evolutionary capability to adapt to all these changes, most of the threats we commonly encounter do not require an immediate response (see Chapter 4). Thus, the evolved response is often blocked and we are obliged to find other ways of coping with threats. It is the experiences that result from blocking the FoF response that are referred to as stress.

To counterbalance the stress response, evolution has also provided us with a relaxation response. This becomes operational when a threat passes and the body reverts to more normal functioning through a relaxation process in which the phenomena described in Summary Text 6.1 are reversed. Generally, both the stress response and the relaxation response are not under voluntary control, being governed by the involuntary (or autonomic) nervous system, which has two branches: the sympathetic branch governing the stress response and the parasympathetic branch controlling the relaxation response via

SUMMARY TEXT 6.1 Characteristics of the Flight or Fight Response

- Pupil dilation and increased sensory perception (increases capacity to take in relevant stimuli from the environment)
- Involuntary vocalization (crying out—as for a warning)
- Reduced salivary secretion (dry mouth) and inhibited gastric activity (conserves blood for the muscles)
- Hyperventilation and irregular breathing (increases amount of oxygen required to run away or fight)
- Increased blood pressure, pulse rate, and peripheral circulation plus reduced bleeding (increases flow of oxygenated blood to the muscles)
- Increased muscular tension, capacity, and activity (state of readiness for action)

At a neural and endocrine level, the stress response system involves activation of the hypothalamic-pituitary-adrenal circuit. When sympathetic responses arrive, the body's initial endocrine response to stress comprises medullary epinephrine (adrenalin), and cortical steroid from the adrenal gland. This operates via projections from the central amygdala to the bed nucleus of the stria terminalis and paraventricular hypothalamus, where, corticotropin-releasing factor influences release of corticotropin from the pituitary, which initiates corticosteroid hormone release from the adrenal cortex. The lateral hypothalamus projects to sympathoexcitatory brainstem nuclei, which control peripheral organs (pupils, salivary excretions, respiration rate, blood flow, etc.) via the sympathetic ganglia. Further details are in Labar and LeDoux (2011).

the vagal nerve—the relative strength of the relaxation response being measured as vagal tone. The voluntary nervous system activates all the behavior that we choose to undertake, including putting ourselves into stressful situations. However, various coping responses, described later in this chapter, can be brought under voluntary control so that they can influence the stress and relaxation responses.

One problem with a multidimensional concept such as stress is the large number of variables that can be associated with it. For example, almost anything we encounter in life may be a potential stressor, depending upon our perception or attitude to it at the time. Some writers (Briner & Reynolds, 1993) have criticized this loose approach to stress on the grounds that there are too many variables for sensible study and that causal links between them are either very small or impossible to detect. Some examples of variables that have been associated at some time with stress are shown in Summary Text 6.2. Clearly, not all the features described will affect everyone, but a combination of some of these, together with others not mentioned, are likely to be experienced by most people for at least some of the time. Holmes and Rahe (1967) allocated points for various significant life events (e.g., bereavement, marriage, divorce, moving house), which they alleged could produce stress in people. This was used to produce a cumulative score, which would indicate a person's critical stress level. However, subsequently it was found that daily hassles, such as household concerns, time pressures, inner concerns, and financial and work issues produced more stress than much less common major life events (Kanner, Coyne, Schaefer, & Lazarus, 1981).

The experience of stress often results in symptoms, both in the short term and long term, in a wide variety of possible ways. Short-term effects may be annoying, but long-term

SUMMARY TEXT 6.2 Pressures That Can Act as Stressors

Life pressure inter alia from: Community (keeping up with neighbors), noise (e.g., traffic, aircraft, neighbors), marital disharmony, sex (e.g., lack of), conflicts with children, ethnic relations, gender relations, medical condition, finance, diet, inadequate housing, bereavement, traumatic experience, driving, and physical danger.

Organizational pressure inter alia from: Role ambiguity, role or interpersonal conflict, role overload (too much work), responsibility for others, organization size, abilities inadequate for task, task makes too few demands, lack of opportunities for self-development, fluctuating workload, lack of control over job, lack of participation, poor communication, poor relations with colleagues, discriminatory practices, unsettling industrial relations problems, lack of feedback on work performance, not appreciated, not promoted, too little scope for initiative, position in hierarchy, organizational culture, change processes, and threat of, or actual redundancy.

Job pressure inter alia from: Ambient environment (too hot/cold), other physical hazards, others smoking, harassment, overcrowding, workplace layout, workplace design, job design, poor welfare facilities, excessive workload, unreasonable production targets, machine pacing, repetitive work, long working hours, restricted social contact, shiftwork, conflict with superior, workgroup demands for conformity, having a sedentary job, heavy work, vibration and motion, pollution, and perceived dangers.

chronic stress effects are most likely to be damaging. Effects of stress are generally identified as being physical/physiological, psychological (cognitive), emotional, behavioral, and medical—some of the main ones are identified in Summary Text 6.3. Stress indicators are many and varied, affecting individuals and organizations as well as families and other groups.

While the experience of psychological strain may be temporary, experience of one strain can increase vulnerability to other types of strain; for example, the long-term effects of job dissatisfaction may include physical ill-health and poor psychological well-being. As far as long-term medical effects are concerned, the process that seems to operate is that the stress response, if unrelieved over time, can eventually reduce immune system effectiveness, thereby decreasing our defenses against physical disease and illness (Segerstrom & Miller, 2004). There is substantial evidence to link stress with high blood pressure and heart disease (Chandola, Brunner, & Marmot, 2006; Cooper, 1996), cancer (Cooper & Watson, 1991), type 2 diabetes (Chandola et al., 2006; Kisch, 1985), irritable bowel syndrome, and skin problems, such as eczema (Quick & Quick, 1984), as well as various other conditions. Cohen, Tyrrell, and Smith (1991) found that people were more prone to catching colds when under stress, suggesting immune function impairment. Other studies have found reduced immune system effectiveness to be associated with stress (Kiecolt-Glaser et al., 1987). At a cellular level, it has been shown that chronic stress affects the ability of the body's cells to divide and to remain healthy, hastening the aging process as well as compromising immune function (Epel et al., 2004). Nevertheless, the overall picture is complicated by finding that individuals, who have the highest levels of psychological well-being, do not necessarily have the most robust immune systems (Segerstrom, 2007).

SUMMARY TEXT 6.3 Indicators of Strain

Physiological: Increased secretion of catecholamine, adrenalin, and cholesterol, raised blood pressure (hypertension), increased heart rate, dryness of throat and mouth, loss of/excessive appetite, and hyper-excitation.

Physical: Increased muscular tension, changes in breathing rate, elevated pulse, cold hands and feet, perspiration, sleeplessness, constant tiredness, headaches, backaches, indigestion, nausea, trembling, frequent urination, diarrhea, elevated voice pitch, circles under the eyes, restlessness, blurred vision, skin rashes, colds and minor illnesses, and change in sexual response (e.g., impotence).

Emotional: Greater displays of emotion, depression, irritability, anger, low self-esteem, apathy, anxiety (state), development of phobias (irrational fears), nervous laughter, defensive reactions to other people's remarks, more judgmental of self and others, emotional withdrawal, emotional outbursts, crying, hostile feelings, frustration, tension, boredom, irritability, monotony, and unreality.

Psychological (cognitive): Inability to concentrate on tasks, sudden change in ways of thinking about or dealing with tasks, tendency to make more mistakes, difficulty in making simple decisions, increased forgetfulness, general decrease in performance, tendency to lose perspective, excessive daydreaming and fantasizing, less rational thinking, reliance on old programs, inability to concentrate, increased caution, and poor judgment.

Behavioral: Sudden changes in work (e.g., personal) habits (e.g., hygiene), lethargy, nervous laughter, increased use of nicotine/alcohol/other drugs, increased absenteeism, poor timekeeping, increased labor turnover, increased requests for early retirement, increased injury rate, increased disputes/strikes, refusal to take orders, alienation, speeded up (manic type) behaviors, avoiding work and other obligations, speech difficulties, increased clumsiness, increase in compulsive behaviors (e.g., shopping, cleaning), change in food intake, impulsive behavior, easily startled, taking too little exercise, taking shortcuts, loss of interest in work, decrease in work performance, petty theft and vandalism (e.g., at work), sabotage, short tempered, inefficiency and incompetence (e.g., at work), inability to maintain personal relationships (at home and at work), low morale, reduced product quality, low productivity, marital and family breakdown, and social isolation.

Medical: Coronary heart disease, hypertension, stroke, ulcers (gastric, intestinal), colitis, irritable bowel syndrome, constipation, migraine headaches, allergies, asthma, hay fever, skin conditions (e.g., dermatitis), cancer, rheumatoid arthritis, multiple sclerosis, myalgic encephalomyelitis, diabetes mellitus, injuries, obesity, (various) mental disorders (e.g., neurosis, mental breakdown), chronic insomnia, nightmares, panic attacks, and suicide.

6.2 Models of occupational stress

Sources of occupational stress include physical aspects of the working environment, such as noise and lighting, and psychosocial aspects, such as workload, which vary in importance, depending on the job. For example, health care professionals may experience high workload, long work hours, time pressure, and inadequate free time

(Sutherland & Cooper, 1990; Wolfgang, 1988), while money-handling and the threat of violence at work can be stressors for bus drivers (Duffy & McGoldrick, 1990). Sources of pressure derive not only from inherent job factors, but also from the organizational context, such as the structure and climate of the organization (e.g., management style, level of consultation, communication, politics). Organizational stressors can have more impact, even in seemingly stressful jobs, than can intrinsic job factors, for example, for police (Hart, Wearing, & Headey, 1995; Thompson, Kirk–Brown, & Brown, 2001), ambulance staff (Glendon & Coles, 2001), and teaching occupations (Bradley, 2007, 2010; Hart, 1994). Rather than harrowing aspects of the job such as attending road traffic collisions, Hart et al. (1995) found that daily hassles associated with police organizations (e.g., communication, administration) were the main predictor of psychological distress among police officers. Sparks and Cooper (1999) emphasized the need to measure a broad range of stressors in order to reflect different situations. Empirical studies have found that job-specific stressors are important in predicting outcomes for particular occupations (e.g., general practitioners, Cooper, Rout, & Faragher, 1989; anesthetists, Cooper, Clarke, & Rowbottom, 1999), while generic stressors vary between occupational groups (Sparks & Cooper, 1999). Significant differences have also been found between workgroups and between departments within organizations, reflecting different subcultures (Cooper & Bramwell, 1992).

Sparks, Faragher, and Cooper (2001) identified four sources of occupational stress, which have grown in importance, given the nature of recent changes in the modern business world: job insecurity, long work hours, control at work, and managerial style. To which might be added changes in technology, such as smartphones and wireless technologies, which allow employees to work around the clock outside traditional work settings. Research has shown that increased use of such technologies can lead to an expectation of almost instant response to messages (e.g., e-mail), and subsequent feelings of pressure and intrusion (Rosen, Carrier, & Cheever, 2013). For teleworkers (such as homeworkers) who work away from traditional work settings via technology, additional pressures can come from feelings of isolation (Koehne, Shih, & Olson, 2012). Trends in working practices across Europe have witnessed an increase in work pace (Paoli, 1997) and the emergence of alternative work schedules, with some employees completing work shifts in excess of 8 h (Hewlett & Luce, 2006; Rosa, 1995); others work compressed schedules so that a working week of 36–48 h may be completed in three or 4 days (Sparks et al., 2001). There is considerable variation in typical working patterns in terms of work hours, but a pattern is emerging whereby employees tend to work both shorter (<30) and longer (>50) hours than the traditional 40 h week, including in the United States (Jacobs & Gerson, 2004), Australia (Drago, Wooden, & Black, 2009), and European countries, including the United Kingdom (Kirkcaldy, Furnham, & Shepard, 2009), and Norway (Wagstaff & Lie, 2011). Although teleworking has increased, employees are also spending more time commuting (Kirkcaldy et al., 2009) adding to the hours spent working. There is considerable evidence that longer work hours have negative effects on employees' health and well-being, including increased risk of heart disease (Virtanen et al., 2012), type 2 diabetes (Tayama, Li, & Munakata, 2015), and psychological well-being (Burke & Fiksenbaum, 2008).

The psychological contract between employer and employee is often undermined to the extent that many employees no longer regard their work as secure (Cooper, 1999). This can be reflected in employee perceptions of job insecurity, with serious effects on health and well-being in European employees (Borg, Kristensen, & Burr, 2000; Domenighetti, D'Avanzo, & Bisig, 2000). North American employees are experiencing similar effects; for example, McDonough (2000) found that, for Canadian employees, perceived job insecurity was significantly associated with reduced general health and increased psychological distress. The introduction of lean production methods has resulted in negative effects on psychological outcomes, including employee well-being (Parker, 2003). Although researchers have examined many of the negative effects of the changing world of work, a limited number of studies has explicitly examined effects on safety-related outcomes. One possible mechanism for the impact of workplace characteristics on safety outcomes is mediated by the effects of occupational stress. Indeed a health impairment pathway has featured in some safety models (Clarke, 2010; Nahrgang, Morgeson, & Hofmann, 2011).

Reviews have indicated that psychological strains, such as anxiety and depression, are strong correlates of work-related stressors (Jackson & Schuler, 1985; Jex & Beehr, 1991; Kahn & Byosiere, 1992). Van der Doef and Maes (1999) found that two-thirds of the studies that they reviewed supported an association between work-related stressors and psychological well-being; a finding that has been replicated in longitudinal research, supporting the influence of stressors on psychological strain (de Lange, Taris, Kompier, Houtman, & Bongers, 2003), in relation to a range of health outcomes (Parker et al., 2003). Viswesvaran, Sanchez, and Fisher (1999) estimated an effect size of 0.43 between the general constructs of work stressors and strain. Considerable focus has been placed on the antecedents of an extreme form of psychological strain, burnout—a psychological phenomenon characterized by prolonged exhaustion and disinterest (Maslach, Schaufeli, & Leiter, 2001). In a meta-analysis, Lee and Ashforth (1996) found strong support for the effects of work stressors on burnout (effect size > 0.50).

Much of the stress literature focuses on health-related outcomes of stress, while behavioral responses to stress, including job performance, turnover, absenteeism, use of alcohol, smoking, substance use, and destructive behaviors, have received less attention (Cooper, Dewe, & O'Driscoll, 2001). Research has also highlighted the important role that these behaviors play in mediating the effects of stressors on health outcomes (Jones, Conner, McMillan, & Ferguson, 2007).

6.2.1 Transactional model

Contemporary definitions of stress generally adopt a transactional perspective. This emphasizes that stress is located neither in the person nor in the environment, but in the relationship between the two (Cooper et al., 2001; Griffin & Clarke, 2011). Within this perspective, the term *stress* refers to the overall transactional process, rather than to specific elements of the process, such as the individual or the environment. Stress arises when an individual appraises the demands of a particular encounter as about to exceed available resources and, therefore, to threaten their well-being, and necessitates a change in individual functioning to restore the imbalance (Lazarus & Folkman, 1991).

The transactional model has two stages to appraising a threat (potential stressor). In the primary appraisal stage the individual asks, "Is this situation important to me?" and "Is it challenging or threatening?" If the situation is appraised as being important, then at the secondary appraisal stage the individual asks, "How can I cope with it (options are considered, for example, using past experience of similar situations)?" "Can I affect the situation (control)?" and "What resources (e.g., social support from colleagues) are available to me?" In reality, secondary appraisal (perceived coping ability) affects primary appraisal (perception of threat) because a potential stressor that can be readily dealt with will not remain a threat. For example, if the individual is confident, on the basis of past experience that they can cope with the situation then it will not be perceived as threatening. Stressors refer to events that are encountered by individuals; strain refers to the individual's psychological, physical, and behavioral responses to stressors (Beehr, 1998). Stressors take the form of pressures that are mediated by various environments. Effects of stress can take a variety of forms including, psychological, physiological, and behavioral. In response to a threat from stressors, coping mechanisms serve to reduce their impact upon the individual. One way in which an individual may seek to cope is by tackling the causes of stress directly (problem-focused coping); an alternative (though not mutually exclusive) approach is for the individual to change the way she/he feels about the situation (emotion-focused coping).

6.2.2 Job demands–resources model

The job demands–job resources (JDR) model (Demerouti, Bakker, de Jonge, Janssen, & Schaufeli, 2001) proposed that work outcomes are the product of work characteristics deemed to be either job demands or job resources. Job demands are defined as, "those physical, social, or organizational aspects of the job that require sustained physical or mental effort and are, therefore, associated with certain physiological and psychological costs," while job resources are defined as, "those physical, social or organizational aspects of the job that may do any of the following: (1) be functional in achieving work goals; (2) reduce job demands and the associated physiological and psychological costs; (3) stimulate personal growth and development" (p. 501). Thus, the definition of these terms is quite broad and potentially includes a wide variety of work characteristics. The JDR model builds on earlier models, including the demands-control (DC) model (Karasek, 1979; Karasek & Theorell, 1990), the demands-control-support (DCS) model (Johnson, Hall, & Theorell, 1989) and the burnout model (Lee & Ashforth, 1996). In the DC model, job demands and job control play an important role in the effect of stressors on strain; in particular, job control (or decision latitude) acts as a moderator, such that high control mitigates the adverse effects of excessive job demands on strain (Karasek & Theorell, 1990). The DCS model added social support as a buffer of the stressor-strain relationship. In terms of the JDR model, both job control and social support would be considered as resources.

The model proposes that two central processes link work characteristics to outcomes: health impairment pathway and motivational pathway. A combination of high demands and low resources will lead to burnout (over time) via the health impairment pathway; while high resources will increase work engagement, leading to enhanced performance, via the motivational pathway. Empirical evidence has provided strong support for the main effects of job demands and job resources in relation to burnout and engagement, with some evidence of predicted interactional effects (e.g., Häusser, Mojzisch, Niesel, & Schulz-Hardt, 2010). Although most evidence has been cross-sectional in nature, some longitudinal studies have supported the effects of demands and resources on later burnout (Schaufeli, Bakker, & Van Rhenen, 2009) and work engagement (Hakanen, Schaufeli, & Ahola, 2008).

6.2.3 Conservation of resources model

The conservation of resources (COR) approach to stress proposes a key role for resources, in which individuals seek to acquire, protect, and conserve resources (Hobfoll, 1989). Personal resources (e.g., time, attention, energy) are limited and, given their importance for adaptive functioning, must be preserved. Individuals strive to gain resources and any threat of resource loss, or failure to gain sufficient resources, may result in strain. In the COR model, job demands act to deplete resources, which in turn leads to maladaptive coping and strain. The main process in this model is motivational, as individuals are motivated to prevent the depletion of resources. The loss of resources (whether perceived or actual) can lead to psychological stress (Brotheridge & Lee, 2002). Burnout occurs over time, as continued experience of high demands and depleted resources leads to further erosion of resources (e.g., energy, self-efficacy). Positive gain spirals are also predicted by COR theory, whereby the accumulation of personal resources increases work engagement, which in turn leads to further expansion of resources (Hobfoll, 2002). The cyclical nature of these relationships has received empirical support (e.g., Xanthopoulou, Bakker, Demerouti, & Schaufeli, 2009).

6.2.4 Challenge-hindrance model

The challenge-hindrance model (LePine, Podsakoff, & LePine, 2005) proposed that work stressors may be defined as either challenges (i.e., demands or obstacles that can be overcome with extra effort to result in the accomplishment of goals and the potential for personal growth), or hindrances (i.e., demands that are appraised as threatening and unmanageable, and so may be viewed as obstacles to personal growth). The challenge-hindrance model predicts that while both types of stressor will lead to job strain, there will be differential effects in relation to affective response, attitudes, and job performance. In support of the model, LePine et al. (2005) demonstrated that both hindrance ($\beta = 0.50$) and challenge ($\beta = 0.23$) stressors were associated with increased job strain. Research has also supported the differential relationship with other work outcomes (Cavanaugh, Boswell, Roehling, & Boudreau, 2000; Podsakoff, LePine, & LePine, 2007).

Hindrance stressors (including organizational constraints, hassles, role ambiguity, role and interpersonal conflict, role overload, and job insecurity) are predicted to have negative affective and behavioral outcomes, as they are unlikely to be overcome by the employee, even with extra effort. Empirical work has supported a negative association with job satisfaction (Cavanaugh et al., 2000; Podsakoff et al., 2007; Webster, Beehr, & Christiansen, 2010), and job performance (LePine et al., 2005; Wallace, Edwards, Arnold, Frazier, & Finch, 2009), and a positive association with turnover intentions (Podsakoff et al., 2007).

Challenge stressors (including workload, time pressure, job scope, and responsibility) are demands or obstacles that can be overcome with extra effort to result in the accomplishment of goals and the potential for personal growth. They have been positively associated with job satisfaction (Podsakoff et al., 2007; Webster et al., 2010) and job performance (LePine et al., 2005; Wallace et al., 2009).

6.3 Workplace stressors, safety behavior, and injuries

Stress is considered to be responsible for 60%–80% of all workplace injuries (Cooper, Liukkonen, & Cartwright, 1996). This is reflected in empirical studies, which have found that working in a stressful environment is associated with higher levels of workplace injuries. For example, in a study of 778 vets, Trimpop et al. (2000) used a job stress questionnaire to gauge the presence of stress in the working environment (e.g., "I experience permanent stress involving the working atmosphere," and "I find my work strenuous"); job stress was a predictor of work injuries. Kirkcaldy et al. (1997) found that job stress among a sample of 2500 doctors was a major predictor of work-related injuries and incidents. In a national sample of 24,486 French employees who completed a self-report questionnaire, Niedhammer, Chastang, and David (2008) found that high psychological demands were associated with higher levels of work injury.

Experience of workplace stressors may have direct effects on employees' safety-related performance, which subsequently increases injury liability. Alternatively, effects may be indirect, for example, being mediated by employee health and well-being. Exposure to long-term stressors is likely to result in psychological and physical symptoms of ill-health (e.g., depression, dissatisfaction, physical illness)—symptoms that can lead to lower performance and increased injury risk. For example, in a study of junior house officers, Houston and Allt (1997) found that psychological distress was linked to significant medical errors, as well as with everyday errors, supporting an association between stress symptoms and human error in organizations. In a maritime environment, Wagenaar and Groeneweg (1987) found that personnel made more frequent errors under high situational stress than would be expected by chance, and that social pressure had a greater influence on job performance than did formal rules and procedures. Cooper and Cartwright (1994) identified individual symptoms (e.g., depressed mood and raised blood pressure) as leading to mental and physical ill-health, and also organizational symptoms (e.g., high absenteeism, high labor turnover) that led to frequent and severe injuries. This indicated that stress may also have organizational level effects that increase injury likelihood; for example, high absenteeism may lead to staff shortages, thereby increasing workload on remaining personnel and making errors more likely.

The empirical work reviewed suggests that stressors at work contribute significantly to workplace injuries. However, there is also limited evidence to support a relationship between job stress and work-related injuries, such as vehicle crashes. Gulian, Glendon, Davies, Matthews, and Debney (1990) found that driver stress in a sample of United Kingdom drivers was associated with reports of work stressors, such as worries about redundancy and retirement. The authors suggested that work demands could influence some drivers' general attitude and reactions toward driving. However, these results were not repeated in a sample of Japanese drivers (Matthews, Tsuda, Xin, & Ozeki, 1999), where relatively small associations were found between occupational stressors, such as work demands and driver stress. Trimpop et al. (2000) found that for a sample of veterinary surgeons, job stress was significantly correlated with work injuries but not with car crashes.

Workplace stressors that have been investigated by researchers in relation to work injuries have focused on intrinsic job characteristics (e.g., quantitative workload, work schedules, exposure to risk/hazards), organizational roles (e.g., role ambiguity, role conflict, role overload), relationships at work (e.g., quality of interpersonal relationships, lack of social support from others in the workplace), job insecurity, and the work-home interface. These are discussed in the following sections.

6.3.1 Workload and work pace

Investigations of perceived time pressure and work demands upon work injuries have revealed mixed results. In some studies work pressure has been associated with injuries, while in other studies little association has been found. Work demands may have direct effects on injury risk as employees who perceive that they are under pressure to increase production may deviate from safety rules that impede their progress, or perform tasks with less care, thereby increasing the likelihood of errors. Work pace (Cooper & Phillips, 1994; Zohar, 1980) and conflicts between safety and production (Díaz & Cabrera, 1997; Mearns, Flin, Gordon, & Fleming, 1998) have both emerged as significant factors in the safety literature. On the other hand, time pressure and increased workload may increase the level of attention paid to tasks, and increase the need to be vigilant for errors.

Quantitative overload may be represented as having too much to do in too little time. While some people put great pressures on themselves and others, overload can result from insufficient delegation and poor time management. An extreme instance of job overload is trauma associated with work. Greiner et al. (1998) used observational job analysis to measure stress factors for 308 transit operators performing driving tasks. Two stressors that were significantly related to vehicle crashes were time pressure and time binding (autonomy over time management). The risk of vehicle crashes was significantly increased for high time-pressure operators and for the medium time-binding group. The findings suggested that job design changes that reduced time pressure to meet deadlines and increased control over the timing of tasks, such as guaranteed rest breaks and flexible timing, would help to reduce vehicle crashes. Matthews and Desmond (2001) outlined strategies for reducing stress in a driving context through design and training techniques.

Perceived job demands (measured using the Job Content Questionnaire) were significantly related to injury severity in a study of construction workers who had suffered falls (when confounding variables were controlled), such that higher job demands were associated with *less* severe injuries (Gillen, Baltz, Gassel, Kirsch, & Vaccarol, 2002). An important variable to consider, in addition to the level of work demands, is the degree of autonomy or control that employees can exercise over the work environment, as control over workload may mitigate potentially adverse effects on work outcomes (see Section 6.2.2 on the JDR model). In Greiner et al.'s (1998) study, in addition to work demands, time binding (autonomy over time management) was a significant variable. Although Gillen et al. (2002) found the interaction between job demands and decision latitude was not significant, they noted that, "although most reported high psychological job demands, they also reported a high degree of decision latitude" (p. 46). Studies have supported a relationship between autonomy and work injuries (Harrell, 1990; Hemingway & Smith, 1999), indicating that greater job autonomy is associated with fewer injuries. Parker, Axtell, and Turner (2001) found a significant relationship between job autonomy and safe working. This relationship was fully mediated by organizational commitment, indicating that level of perceived control affected the degree to which employees felt committed to their organization, which in turn led to more positive safety behavior. Implications of these findings for managing many workplace risks could include ensuring that once people are skilled and competent at their jobs, in most cases they should be given sufficient autonomy to perform without interference. In some circumstances, particularly where employees are able to exercise autonomy over their work, over-supervising could reduce safety.

Mechanisms linking work pressure to employees' safety-related behavior would include the effects on following rules and regulations (i.e., safety compliance). In Elfering, Semmer, and Grebner's (2006) study, stressful events were recorded in pocket diaries by 35 novice nurses. Stressors were also recorded using observations and a safety compliance survey. Across stressful events, the observed level of concentration demands was significantly associated with lower safety compliance (Elfering et al., 2006), suggesting that increasing demands may encourage employees to take shortcuts in order to save time and effort. Hansez and Chmiel (2010) found that work overload had a small but significant association with routine violations (deviations from rules and procedures); but that higher levels of decision latitude were associated with fewer routine violations. Again, this would indicate that job resources (such as decision latitude) may mitigate the effects of work demands. The moderating effect of job control is discussed further in Section 6.6.1.

As well as overload, job underload, such as repetitive, boring, routine, and under-stimulating work, has been associated with occupational stress. Cox (1985) described repetitive work as a discrete set of activities, repeated over and over again in the same order without planned interruptions by other activities or tasks. Activities are simple and unskilled, often with a short time cycle. Many jobs involve inevitable periods of boredom, even when task performance is critical for safety, for example, pilots or air traffic controllers, and boredom or disinterest in a task may adversely affect employee responses to emergencies. Strategies used, for example, by assembly workers for coping with repetitive and monotonous tasks include switching off and letting the mind go blank. The nature of repetitive work varies between jobs, as do individuals' susceptibilities to stress from such work.

A further source of dissatisfaction and stress could be lack of control over the task, with many employees enjoying little autonomy or responsibility. Underused skills and knowledge are frequently associated with repetitive work, as are high levels of machine pacing, often at relatively isolated workstations with reduced social contacts, low job complexity, and a lack of participation. Employees engaged in repetitive work suffer poorer health than do those in other occupational groups, which could be exacerbated by shiftwork that involves night working (Cox, 1985). In their study of repetitive work, pacing and short time cycle at a large car factory, Broadbent and Gath (1981) used the following health indices: anxiety (feelings of tension and worry), depression (lethargy, inability to make an effort), somatic symptoms (e.g., stomach upsets, giddiness), and obsessional problems (e.g., perfectionism, failures in control due to unwanted thoughts). From the findings, it seemed that pacing rather than short cycle times is a health hazard, and that people can become stressed without being dissatisfied with the job. Again there are indications that attention to managing risks of repetitive work could pay dividends in terms of better employee health.

6.3.2 Work schedules and shiftwork

Studies have found shiftwork to be a stressor, particularly where it involves night work, the most obvious manifestation being disturbance of sleep patterns (e.g., Dembe, Erickson, Delbos, & Banks, 2006). Further research findings can be found as follows, regarding the effects of sleep and circadian rhythms on performance (Campbell, 1992), effects of time of day and performance (Smith, 1992), sleep deprivation (Benavides, Benach, Diez-Roux, & Roman, 2000; Tilley & Brown, 1992), vigilance (Nachreiner & Hänecke, 1992), and acute and chronic fatigue (Craig & Cooper, 1992). Other effects include disturbance of neurophysiological rhythms (e.g., blood temperature, metabolic rate), blood sugar levels, mental efficiency, and work motivation. Such effects may ultimately lead to stress-related disease, including heart disease, type 2 diabetes and cancer in long-term shiftworkers (Wang, Armstrong, Cairns, Key, & Travis, 2011). From a review of 14 studies examining the effects of shiftwork and long working hours on injuries, Wagstaff and Lie (2011) concluded that working >8 h led to an increased safety risk, which increased beyond 8 h such that the safety risk after 12 h was twice the risk at 8 h. Although shiftwork and working nights substantially increased safety risk, night work may actually offer some protection due to resynchronization (Wagstaff & Lie, 2011).

Shiftwork may be exacerbated by repetitive tasks, one possible outcome of which is injuries. In a review of shiftwork and injuries, Carter and Corlett (1981) suggested that minor injuries were more likely to be due to overarousal or hyperalertness, associated with careless and disturbed behavior. More serious injuries and errors of omission tended to be due to low levels of alertness and automatic cerebral functioning, for example, in monotonous tasks. Evidence suggests that performance deficits have implications for increased injury risk. For example, assessing the effects on junior hospital doctors of working 32 h on-call shifts, Leonard, Fanning, Attwood, and Buckley (1998) showed adverse effects on psychological well-being and significant detrimental effects on these doctors' alertness and concentration when conducting simple tasks.

6.3.3 Role-related stressors

Various aspects of organizational roles have been identified as sources of occupational stress; role-related stressors comprise role ambiguity, role conflict, and role overload. Role ambiguity (which reflects a lack of role clarity or being unsure of what you are supposed to do) can be distressing because it can lead to feelings of being out of control or being controlled by others. Role conflict (e.g., being expected to do two or more incompatible things) can also be experienced as stressful. Hemingway and Smith (1999) found that role conflict and role ambiguity were significantly related to work-related injuries for 252 Canadian nurses. The authors suggested that lack of job clarity could have a direct effect on injuries as this often led to the individual operating in unfamiliar situations, thereby increasing injury likelihood. In contrast, studying a sample of 362 Australian blue-collar manufacturing employees, Iverson and Erwin (1997) failed to find significant associations between role ambiguity or role conflict, and occupational injuries. However, finding that employees undertaking more routinized jobs sustained fewer injuries, these authors suggested that employees undertaking routinized jobs were assigned less responsibility, which decreased their probability of injury, a finding supported by other studies (Hansen, 1989; Harrell, 1990). Hansez and Chmiel (2010) found that higher role ambiguity was associated with greater frequency of routine violations. This relationship was mediated by job strain, demonstrating that role ambiguity can have both direct effects in relation to injuries, but can also affect behavior through mediating effects of job strain. Role overload (e.g., having too many tasks to complete as part of your role) has been associated with increased safety risk. For example, Turner, Chmiel, Hershcovis, and Walls (2010) examined the effects of role overload in a sample of railway track workers and found a significant relationship with higher frequency of hazardous work events (i.e., situations where there was a danger of physical injury).

Problems connected with role-related stressors were demonstrated in a study of dentists (Cooper, Mallinger, & Kahn, 1978). Considering themselves to be inflictors of pain rather than healers, the dentists felt that their clinical role clashed with other nonclinical roles, such as performing administrative duties and building up their practice. In addition, their work roles interfered with their private lives. One adverse health outcome associated with the dentist's role was abnormally high blood pressure. Where a role entails responsibility for people and their safety, there is potential for occupational stress. For example, responsibility for people's safety and lives was identified as a major source of long-term occupational stress for air traffic controllers (Crump, Cooper, & Maxwell, 1981). Carrying out work roles often involves developing relationships with others. Poor relationships with one's superior, colleagues, and subordinates have been related to occupational stress, which may result in psychological strain and job dissatisfaction; good work relationships tend to have the opposite effect.

6.3.4 Work relationships

Evidence suggests that the quality of interpersonal relationships and communication are significantly associated with work injuries. Trimpop et al. (2000) found that working climate (communication and relationships with staff) was significantly related to work injuries. From a longitudinal study of 161 manufacturing employees' self-reported safe working practices, Parker et al. (2001) found that communication quality had a significant positive relationship with safe working. Effective communication helps to clarify to employees what they are expected to do and how this should be completed, facilitating safety compliance.

Studies investigating the role of social support from coworkers and supervisors in relation to safety have suggested an association with lower injury rates (Iverson & Erwin, 1997; Sherry, 1991). In organizational settings, immediate colleagues and first-line supervisors often provide social support. Supervisory support has been simply defined as amount of consideration expressed by an immediate supervisor for subordinates (Michaels & Spector, 1982), and coworker support as amount of consideration expressed by coworkers (Blau, 1960). In terms of injury reduction, social support could take an informational role, by providing information to employees on how to deal with safety-related problems, having a direct effect on employee behavior. It could also have a buffering effect, reducing psychological strain associated with workplace stressors, by providing instrumental support (by helping an individual attend to their problems) and emotional support (by modifying their perception that the stressor is damaging their well-being). Buffering employees against psychological strain, particularly over time, could help to ameliorate adverse effects on job performance associated with mental and physical ill-health. However, in terms of managing the risks, effort is required to sustain those effects in the longer term.

Examining supervisory and coworker support in relation to occupational injuries experienced by Australian manufacturing workers, Iverson and Erwin (1997) found that supervisory and coworker support had a negative relationship with occupational injuries, such that greater support was associated with fewer injuries. In this setting, the relationship was thought to stem from supervisors and coworkers providing greater levels of task and informational assistance to employees in carrying out their jobs, that is, increased level of informational support. Hemingway and Smith (1999) reported similar findings in a study of occupational injuries among nurses, which included supervisor support as an element of organizational climate. Supervisor support was negatively correlated with unreported injuries and near injuries (but not with reported injuries). Significant correlations were also found with peer cohesion for reported injuries and near injuries, indicating that a close relationship with colleagues was associated with fewer injuries. In a longitudinal study of manufacturing employees, Parker et al. (2001) found that supportive supervision had a lagged positive effect on safe working 18 months later. Therefore, there is consistent evidence of a significant relationship between social support, particularly from supervisors, and occupational injuries/safe working, suggesting that social support encourages safer working and reduces the number of occupational injuries experienced by employees.

Hofmann and Morgeson (1999) found that high-perceived organizational support was predictive of safety communication, which in turn indirectly affected injuries via safety commitment. Examining supervisor support for safety separately from management support, Thompson, Hilton, and Witt (1998) found that these two variables mediated different relationships: supervisor support mediated the relationship between supervisor fairness and safety compliance, while management support mediated the relationship between organizational politics and safety conditions. Parker et al. (2001) reported a significant positive relationship between supportive leadership and safety communication, with a lagged effect on safety compliance behavior. This research indicated that supportive supervisors built more positive relationships with their subordinates, and encouraged more open, informal communications, which led to higher levels of safety commitment and compliance among employees.

Other studies have employed measures reflecting social support that have a more specific emphasis on safety. The instrument employed by Oliver, Cheyne, Tomás, and Cox (2002) gauged safety support and behavior and was based on measures developed by Meliá, Tomás, Oliver, and Isla (1992). Supervisory support reflects supervisors' attitude toward safety, positive or negative contingencies that the supervisor gives and supervisors' safety behavior. Tomás, Meliá, and Oliver (1999) reported significant positive relationships between employees' safe behavior and both supervisory response and coworkers' responses. Social support, measured by supervisory support and coworker support, included by Oliver et al. (2002) as organizational involvement, had a significant direct effect on injuries, but also significant indirect effects, mediated by general health and safe behavior.

One potential mechanism is that by following rules and regulations, employees will engage in safer work practices (Turner, Stride, Carter, McCaughey, & Carroll, 2012), and commit fewer violations (Hansez & Chmiel, 2010). On the other hand, a lack of social support and poor relationships at work may act as a work stressor for employees (e.g., an unsupportive supervisor can contribute to feelings of job pressure). Turner et al. (2010) found that a lack of perceived social support at all levels (from managers, supervisors, coworkers) was strongly associated with a higher frequency of hazardous work events. There is also evidence to suggest that social support may act as a buffer in the relationship between job demands and safety outcomes (see Section 6.6.2).

6.3.5 Job insecurity

Probst and Brubaker (2001) examined the effects of job insecurity (unemployment threat) on employee safety outcomes. They found job security to be significantly related to safety knowledge, safety motivation, and reported compliance with safety policies. Injuries were predicted by safety motivation, and to a lesser degree, by safety knowledge and compliance. The authors noted that, "workers operating under conditions of job insecurity choose to ignore critical safety policies and cut corners to maintain or increase their production numbers in an effort to retain their job" (p. 155). The relationship between job insecurity and safety motivation was partially mediated by production demands, suggesting that employees who felt less secure perceived a greater emphasis on production, which led to lowered motivation to attend to safety issues. This explanation relates to the notion that we all have finite cognitive resources, which must be divided between concerns; in this case, for job security and maintaining productivity, leaving reduced capacity for safety-related activities (Probst, 2004a). A further, indirect effect could occur via the impact that lack of job security has in terms of increasing job dissatisfaction and psychological distress (such as anxiety). In developing a model of job insecurity, Størseth (2006) found that the effect of job insecurity on increased risk behaviors was mediated by job dissatisfaction, whereas Emberland and Rundmo (2010) found that job insecurity was indirectly related to risk behavior via the impact on psychological well-being. In addition, there is some evidence that certain aspects of safety climate may moderate the relationship between job insecurity and safety outcomes (Probst, 2004b).

6.3.6 Work–home interface

Strain-based work–home conflict has been conceptualized as a workplace hazard and hypothesized as having an impact on employees' safety-related behaviors at work. Cullen and Hammer (2007) found that increased family-to-work conflict (but not work-to-family conflict) was associated with lower safety compliance and lower safety participation (willingness to participate in discretionary safety meetings). In a longitudinal study of manufacturing and service industry employees, Turner, Hershcovis, Reich, and Totterdell (2014) found that both family-to-work and work-to-family conflict predicted workplace injuries 6 months later, the effect of work-home interference being mediated by psychological distress. Based on the COR model of stress, Turner et al. (2014) suggested that work-home interference acted to deplete resources, which in turn reduced psychological well-being and subsequently increased accident risk. Their model was supported, as the effect of work-home interference was fully mediated by psychological well-being.

6.3.7 Challenge and hindrance stressors

The challenge-hindrance model of stress can be used to understand the range of findings discussed in the previous sections. Conducting a meta-analysis of work stressors in relation to safety outcomes, Clarke (2012) coded stressors as either "challenge" or "hindrance" based on Cavanaugh et al.'s (2000) definitions. Challenge stressors (including, job demands, work pressure, time pressure, time urgency, and work overload) were hypothesized to have positive cognitive, affective, and motivational effects on behavior, leading to greater safety compliance and safety participation, and subsequently fewer near-misses and injuries. Hindrance stressors (including, situational constraints, role ambiguity, role conflict, role overload, job insecurity, and work interruptions) were hypothesized to have adverse effects on safety outcomes, as they lead to strain without the compensating effect of increased motivation. Hindrance stressors were associated with lower safety compliance (e.g., reduced diligence in following rules), and safety participation (e.g., less willingness to get involved with safety activities and initiatives), and subsequently more near-misses and injuries. However, challenge stressors had no effects on either safety compliance or injuries (Clarke, 2012). These findings highlighted the particularly negative impact of hindrance stressors, where employees are less likely to maintain compliance with safety procedures or help coworkers, especially when taking shortcuts and bending rules may increase productivity and lead to rewards for meeting related targets (Wallace & Chen, 2006).

6.4 Direct mechanisms linking stress with workplace safety

There appear to be two major ways in which occupational stress affects work injuries: direct effects on employees' behavior; and, indirect effects mediated by employees' health (including psychological well-being and burnout), and work attitudes (Clarke & Cooper, 2004). Several factors moderate the relationship between stressors and stress outcomes, including job control, social support, coping strategies, and individual personality characteristics (see Chapter 7 on personality).

Reason (1995) described an active failure pathway, by which organizational factors led to violation-promoting and error-producing conditions in the workplace, increasing the likelihood of unsafe acts, which can lead to injuries. Job stress can, therefore, directly affect unsafe acts (e.g., mistakes, slips, and lapses that can result in injuries) by generating violation-promoting and error-producing conditions. For example, Reason (1995) listed, "high workload, deficient tools and equipment, time pressure, fatigue, low morale and conflicts between organizational and workgroup norms" among the "local conditions that promote the commission of errors and violations" (p. 1710). Parker, Manstead, Stradling, Reason, and Baxter (1992) distinguished between error-producing factors, which adversely affected information processing, and violation-promoting factors, which influenced attitudes, beliefs, and group norms. Error-producing factors included: high workload, inadequate knowledge, ability or experience, poor interface design, inadequate supervision, change, stressful environment, and mental state (e.g., fatigue, preoccupation, distraction, anxiety). Thus, direct effects of stress on unsafe acts (e.g., errors and violations) are likely to occur as a result of error-producing conditions, such as high workload, stressful environment (e.g., high demands combined with low control), and mental state (e.g., fatigue, distraction, anxiety), and violation-promoting factors, such as low morale and time pressure. Violations, whilst having negative consequences per se, also bring perpetrators into areas of greater risk, where errors are less readily forgiven (Reason, 1995).

Griffin and Clarke (2011) emphasized the dynamic nature of the stress process due to the transaction between the person and environment unfolding over time through a process of mutual influence, such that there are both longer-term and shorter-term dynamics. In the short term, there will be affective (e.g., anxiety) and physiological (e.g., increased adrenalin level) responses to acute stressors that can affect employees' performance. In the longer term, chronic stressors can lead to health problems, such as heart disease, which develop over a period of years (e.g., Chandola et al., 2006). Positive effects from the dynamic process of successfully managing stressors over time can lead to the accumulation of personal resources and the development of psychological resilience. This forms a positive gain spiral as enhanced resilience promotes more effective ways of managing stressors in the future. Reciprocal influences are difficult to demonstrate, but have been supported in longitudinal studies. For example, Frese, Garst, and Fay (2007) found that a positive feedback loop operated between personal initiative and work characteristics over a 4-year period.

6.4.1 Effects of acute stressors

Much research examining the impact of stress on work injuries has focused on the effects of acute stressors (e.g., time pressure, noise, threat, workload) on human performance. Steffy, Jones, Murphy, and Kunz (1986) developed a model of the relationship between stress and injuries in which stressors caused acute reactions (e.g., anxiety, fatigue), which decreased cognitive and performance capacities, such as reaction times and judgment, thereby increasing error likelihood. The increased injury risk is temporary, as alleviation of stress symptoms (e.g., anxiety) resulted in the return of the employee's capacities to normal levels (Murphy, DuBois, & Hurrell, 1986). A stressful environment may also distract employees from the task, increasing error likelihood, encouraging violations, and promoting suboptimal decision making (e.g., Elfering et al., 2006; Wadsworth, Simpson, Moss, & Smith, 2003). Acute stressors can affect the commission of violations by acting as violation-promoting conditions, that is, a temporary effect in which experiencing a stressor (e.g., time pressure) encourages shortcuts and rule bending. Experiencing acute stressors, such as excessive time pressure or work overload, can lead to supervisors turning a blind eye to rule violations in order to reach production targets. Thus, acute stressors can lead to temporary adjustment of what is deemed to be acceptable, thereby placing production over safety as a priority. Risk management implications of such situations could include learning from some of the methods used by so-called high-reliability organizations (Ash & Smallman, 2003; LaPorte & Consolini, 1991; Weick & Sutcliffe, 2001).

A further effect of experiencing high levels of stress symptoms (e.g., unpleasant emotional states, high emotional arousal) is maladaptive decision making (Janis &

Mann, 1977). For example, faulty decision making resulted from the heightened tension experienced as a result of acute stress in the case of the shooting down of an Iranian airliner by the USS Vincennes (see Summary Text 6.4). Ways of coping with psychological stress are characterized by different forms of ineffective information processing strategies (unconflicted adherence, unconflicted change, defensive avoidance,

---

SUMMARY TEXT 6.4 Account of the Shooting Down of an Iranian Airliner by the USS *Vincennes*

The USS *Vincennes* was operating in the Persian Gulf, near the Strait of Hormuz, on the morning of July 3, 1988, when one of its helicopters was fired on by three Iranian gunboats. Five minutes later, *Vincennes* detected an aircraft taking off from Bandar Abbas airport. The ship radioed seven warnings to the plane, to which the aircraft failed to respond. Captain Will C. Rogers III identified the plane as a hostile F-14, approaching at an altitude of about 7000 feet and descending, and ordered two surface-to-air missiles to be fired. It was subsequently revealed that the aircraft shot down by the *Vincennes* was not an F-14 fighter, but an Iran Air Airbus A300 civilian jetliner en route to Dubai. All 290 people aboard (including 66 children) were killed.

On the face of it, it would appear almost inexplicable that a professional and well-trained U.S. Navy crew could make such a mistake: an F-14 fighter plane is much smaller (about one-third of the size) and sleeker than a passenger plane. The Iran Air Airbus was also flying on a recognized commercial route, and had been climbing (not descending) at an altitude of about 12,500 feet (not 7000 feet) when it was shot down. It was also holding a steady speed, and not rapidly approaching the warship, as its captain claimed.

Consideration of the mitigating factors described below can illuminate the captain's decision making under psychological stress:

- Due to the sand haze that shrouded the Gulf, the approaching plane was not visible to the naked eye, so the crew had to depend upon their instrumentation.
- The plane would have appeared as a smaller dot on the radar than might have been expected, as it was flying toward the warship head-on.
- The Bandar Abbas airport, from which the aircraft had taken off, served both civilian and military craft, and acted as the center of Iran's F-14 operations. Aircraft taking off from this airport were automatically tracked.

Although he had initially identified the plane as a commercial airliner, Petty Officer Anderson, could not find the flight listed. Warnings sent out to the aircraft, four over the military emergency channel, and three over the civilian emergency channel, received no response, possibly because all the plane's channels were in use, or the warnings used the wrong frequencies. None of the warnings were broadcast over air traffic control. Andersen then identified the plane as a military aircraft.

- The crew were aware that the previous year the USS *Stark* had been fired upon by a fighter plane, killing 37 U.S. sailors. This would certainly have raised anxiety and expectations.

SUMMARY TEXT 6.5 Ineffective and Effective Information-Processing Strategies

INEFFECTIVE STRATEGIES

- *Unconflicted adherence*: Ignores information about risk of losses, continues present course of action
- *Unconflicted change*: Uncritically changes to new course of action, ignoring risk consequences
- *Defensive avoidance*: Identifies serious risks in both alternatives—three ways of coping through procrastination, shifting responsibility to another, or rationalization (only attending to positive aspects of possible solutions)
- *Hypervigilance*: Obsessed with serious risk of loss, vacillation between alternatives, rapid search for other options—characterized by reduced memory span and simplistic, repetitive thinking (a "panic" reaction)

EFFECTIVE STRATEGY

- *Vigilance*: Identifies and assesses risks, looks for relevant information, and evaluates risks involved in alternatives before making a decision

hypervigilance); in contrast, effective decision making is characterized by vigilance (see Summary Text 6.5).

6.4.2 Effects of chronic stressors

While acute stressor effects are largely cognitive, influencing the way in which individuals process information, chronic stressors (i.e., those continuing over extended time periods) can also affect cognitive processes, but are likely to have more wide-ranging effects on motivation, attitudes, behavior, and physiological function. Exposure to long-term stressors can directly affect performance (Hemingway & Smith, 1999), but can also result in psychological and physical symptoms of ill-health (e.g., depression, dissatisfaction, physical illness), which can lead to lower performance and increased error likelihood.

Evidence suggests that exposure to a stressful working environment has a direct effect on how individuals process information. Hockey, Clough, and Maule (1996) suggested that stress directly affected performance by encouraging shortcuts in cognitive processing as a means of reducing mental effort. Reason (1990) argued that while stress does not cause errors, it can lead to adopting certain cognitive styles that result both in higher rates of absentmindedness and inappropriate coping strategies. This may have continuing effects, as Broadbent, Broadbent, and Jones (1986) demonstrated that high levels of self-reported cognitive failure were related to vulnerability to external stressors. Trainee nurses with higher cognitive failure scores showed significantly higher levels of stress symptoms when working in more stressful environments (Broadbent et al., 1986). Long-term stress may also have an indirect effect via the psychological strain it causes, for example, Houston and Allt (1997) found that psychological distress in doctors was linked with significant medical errors, as well as with everyday errors. Melamed, Luz, Najenson, Jucha, and Green (1989) argued that preoccupation with disturbing work characteristics, such as stressors, could act as a distracting factor, reducing attention to danger cues. This highlights the contribution of job stress to the type of mental state associated particularly with errors arising from preoccupation and distraction.

Experiencing occupational stress in situations characterized by both excessive work demands and psychological distress is significantly associated with fatigue (Hardy, Shapiro, & Borrill, 1997). Rosa (1995) found excess fatigue, sleepiness, and significant loss of sleep to be typical of employees on extended work shift schedules (10–12 h shifts). Moreover, within an extended shift, Rosa, Colligan, and Lewis (1989) found evidence of performance deficits, decreased reaction time and grammatical reasoning performance, as well as higher subjective fatigue after a 7-month period of 12 h shifts (compared with a previous 8 h shift pattern). This evidence suggested that fatigue was significantly associated with work stressors, particularly high work demands and long hours, which resulted in reduced performance and increased error likelihood.

Whilst acute stressors may lead to a temporary adjustment of safety priority (e.g., placing production over safety when under time pressure), when high exposure to stressors comes to be experienced as the norm, rather than the exception, a permanent change in workplace safety climate can occur, such that employees develop negative perceptions of the organization's commitment to safety, as evidenced in actions and attitudes of managers and supervisors.

6.5 *Indirect mechanisms linking stress with workplace safety*

The following sections consider indirect effects of stress on injuries, both in terms of work-related attitudes, such as job satisfaction, as well as general health, well-being, and burnout. In each case, job stress influences a third variable (e.g., attitudes, health), which in turn influences injuries, the effect being indirect or mediated (see Figure 6.1).

6.5.1 *Work-related attitudes*

One possible mechanism for the indirect effects of job stress on injuries is that it is mediated by work-related attitudes, including job satisfaction, organizational commitment, and job involvement. A commonly measured attitude in relation to job stress is job dissatisfaction (or job satisfaction), which is frequently used as an indicator of psychological strain. The link between occupational stress and job dissatisfaction, such that increased stress results in greater job dissatisfaction is well documented (Jackson & Schuler, 1985; Jex & Beehr, 1991; Kahn & Byosiere, 1992). Evidence has also suggested a causal relationship between job dissatisfaction and work-injury involvement. For example, job satisfaction is significantly lower for employees who have experienced a job-related injury

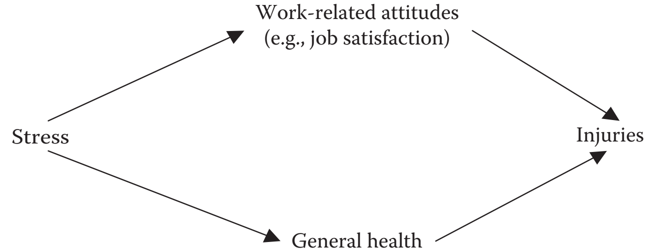


Figure 6.1 Indirect effects of stress on work injuries.

(Holcom, Lehman, & Simpson, 1993; Lee, 1998). In cross-sectional research, it is possible that this relationship reflects a lowering of job satisfaction as a result of experiencing an injury, as well as a causal link between job dissatisfaction and injury involvement. However, in support of a causal relationship, low morale and negative work attitudes are associated with attentional deficits and skill-based errors (Edkins & Pollock, 1997) and are significantly predictive of future errors (Van der Flier & Schoonman, 1988). Probst and Brubaker (2001) found that job-security perceptions were strongly related to job satisfaction, which in turn was an important predictor of safety motivation and knowledge (in both cross-sectional and longitudinal analyses) suggesting that job satisfaction impacts employees' safety behavior. In a meta-analysis to test an integrative model of workplace safety, Clarke (2010) found support for a pathway linking job satisfaction to occupational injuries that was mediated by safety-related behavior.

Job satisfaction is also related to risk perceptions. In hazardous work environments, greater perceived risk is associated with low job satisfaction (Fleming, Flin, Mearns, & Gordon, 1998), and with a lack of satisfaction with both workplace conditions, and work in general (McLain, 1995). These findings suggested that job satisfaction was linked with enhanced safe working, whilst job dissatisfaction was associated with lowered job performance and increased injury liability. Implications for risk management include giving adequate attention to job dissatisfaction and other factors that can potentially affect safety.

There is also support for the hypothesis that experiencing an injury results in lowered job satisfaction. Using a sample of 9908 Australian employees across eight different occupations, Barling, Kelloway, and Iverson (2003) found that workplace injuries resulted in a perceived lack of influence and distrust of management, both of which predicted job dissatisfaction. This might suggest a reciprocal relationship whereby experiencing an injury further exacerbates the job dissatisfaction—injury involvement relationship, making future injuries more likely.

6.5.2 General health

A number of theoretical models of workplace safety have proposed a health impairment pathway, whereby the effects of work stressors on injuries are mediated by general health and well-being, such that the strain caused by stressors reduces general health, which in turn increases accident liability. The link between general health and occupational injuries was supported in Clarke's (2010) meta-analysis.

The injury causation model developed by Oliver et al. (2002) included indirect effects of organizational involvement (supervisor's response, coworker's response, safety management) and the physical work environment (environmental conditions, noise, workload, hazards) on work injuries mediated by general health (anxiety checklist, GHQ anxiety, GHQ depression). A hypothesized meta-analytic JDR-based model was supported by Nahrgang et al. (2011), with the relationship between work demands (workplace hazards, task complexity) and injuries being mediated by well-being. In addition to the impact on work injuries, Hansez and Chmiel (2010) found that the effect of work demands on routine violations was mediated by well-being.

The mediating role of general health supports Cox and Cox's (1993) proposal that stress processes mediate effects of both organizational and physical hazards on the individual. Other research supports an association between health promotion and lower injury rates (Mearns, Whitaker, & Flin, 2003; Shannon, Mayr, & Haines, 1997). Thus, better employee health and well-being may increase stress resilience, thereby reducing injury likelihood. On the other hand, employees suffering psychological distress, such as anxiety and depression, are more prone to errors and injuries. Possible methods of maintaining employee health and well-being in the workplace, such as health promotion programs, are discussed in Section 6.7.

6.5.3 Burnout

Burnout, which is an extreme form of psychological strain, has been studied extensively in relation to workplace stress. It is characterized by emotional exhaustion, cynical attitudes to work and a sense of diminished professional efficacy (Maslach et al., 2001). Nahrgang et al. (2011) identified a positive relationship between burnout and safety outcomes (including adverse events, accidents, and injuries); burnout has also been associated with accident involvement among professional drivers (Chung & Wu, 2013). One potential mechanism for linking burnout to injuries is via the effects of burnout on cognitive functioning. Examining the relationship between surgeons' scores on the Maslach Burnout Inventory and their self-reported clinical errors occurring in the previous 3 months, Shanafelt et al. (2010) found that higher levels of burnout were associated with higher reports of clinical errors. Greater numbers of errors may be due to reduced attentional control, which has been associated with higher levels of burnout (Van der Linden, Keijsers, Eling, & Van Schaijk, 2005).

The effects of burnout, especially emotional exhaustion, have also been examined in relation to the impact on safety-related behaviors (e.g., Halbesleben, Wakefield, & Wakefield, 2010). Based on the COR model of stress, emotional exhaustion will deplete personal resources, such that employees will lack the time, energy or attention needed to follow time-consuming or complicated safety procedures, leading to increased use of "safety workarounds" (Halbesleben et al., 2008; Rathert, Williams, Lawrence, & Halbesleben, 2012). In a cross-lagged study of health care staff, safety workarounds mediated the effect of emotional exhaustion on subsequent injury (Halbesleben, 2010).

6.6 Moderating effects

A number of factors may moderate the relationship between job stress and work injuries, that is, the relationship is stronger or weaker depending on a third variable (the moderator), such as social support or coping strategies employed (see Figure 6.2). For example, strong support from coworkers and supervisors may weaken the relationship between job stress and injuries, such that even where stressors are present, because social support helps to protect the individual from negative effects of stress, these are less likely to result

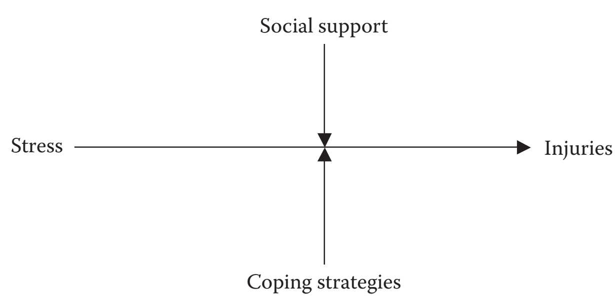


Figure 6.2 Effects of moderating factors on the relationship between job stress and work injuries.

in injuries. Research on the relationship between occupational stress and workplace safety has used the JDR model of stress as a theoretical framework to investigate whether work characteristics that are associated with well-being are also related to safety outcomes at work. Researchers have focused on the potential moderating effects of job control and social support, as discussed in the following sections.

6.6.1 Job control

As discussed previously, both job demands (e.g., work overload, time pressure, organizational role), and job resources (e.g., job control, social support), have main effects on safety outcomes. The JDR model would predict that the main effects of job demands would affect outcomes via the health impairment pathway (i.e., through the effects of strain) and job resources would affect outcomes via the motivational pathway (i.e., through the effects of work engagement). In relation to routine violations, Hansez and Chmiel (2010) found support for the JDR model. Job demands (work overload, role ambiguity) were linked to violations through the effect on job strain, whereas the effects of job resources (decision latitude, work support, job quality) were mediated by engagement. These two major pathways in the JDR model linking job demands and job resources to safety events were also supported in a meta-analytic path analysis (Nahrgang et al., 2011).

The JDR model (and its theoretical predecessors, the DC and DCS stress models) proposed that job control and social support acted as buffers in the stress–strain relationship. In the DC model, the relationship between job demands and job strain was moderated by the level of job control (or autonomy), such that jobs characterized by both high demands and high control do not lead to job strain. In the later DCS model, the moderating effect was extended to include social support. In relation to safety outcomes, researchers have employed the DC model to test the potential moderating effect of job control.

Turner, Chmiel, and Walls (2005) examined the effects of job demands and job control on trackside railway workers' safety. Based on the DC model, in addition to main effects, these authors hypothesized a significant interactional effect of job demands and job control. The safety outcome in this study was safety citizenship role definition, which was defined as employees' role orientation toward improving workplace safety. The proposed demands–control interaction was supported: employees with high demands and high control were more likely to view improving safety as part of their role, than were those with high demands but low control. Snyder, Krauss, Chen, Finlinson, and Huang (2008) found an interaction effect for job demands (situational constraints) and safety control on work injuries, in both a university facilities department sample, and in a sample of pipefitters. Examining emergency department personnel, Turner et al. (2012) found a main effect of job control on safety participation (willingness to engage in safety activities), but no demands–control interaction. Therefore, as with research conducted on the stressor–strain relationship, demands–control interactions have been supported inconsistently in relation to safety.

6.6.2 Social support

The DCS model of stress included the role of social support as a potential moderator of the stressor–strain relationship. This model has been used as a framework to examine the role of social support as a job resource in relation to safety outcomes, both as a main effect and as a moderator of the effects of job demands on safety outcomes. Turner et al. (2010) found a main effect of social support on hazardous work events, such that employees were less likely to experience a hazardous work event when social support (from managers, supervisors, or coworkers) was high. Turner et al. (2010) also found an interaction between job demands (role overload) and social support from coworkers, such that employees with high role overload, but also high coworker support, were less likely to experience hazardous work events. The contribution of coworkers emerged as particularly important in this study as track maintenance workers rely on each other for their safety (given that they often work on the railway line, only having to move away from the track when a train approaches, following the lookout's warning).

Turner et al. (2012) found that social support had an effect on safety compliance (but not safety participation); but that there was no interaction between work demands and social support. In this study, the interaction between job resources (job control and social support) was significant for safety participation. This finding suggested that employees need a high level of job resources (regardless of the level of job demands) to engage in safety related activities. Sampson, DeArmond, and Chen (2014) also failed to support a moderation effect of social support in the relationship between work stressors and safety behaviors. Therefore, as with job control, there is mixed evidence for a moderating effect of social support.

6.6.3 Coping strategies

Most people use a number of different coping strategies to deal with stress (Folkman & Lazarus, 1988). A popular distinction is between problem-focused strategies (dealing directly with the problem) and emotion-focused strategies (dealing with feelings about the problem). In general, proactive problem solving has a more positive effect upon personal well-being (Folkman, Lazarus, Dunkel-Scheffer, De Longis, & Gruen, 1986), while emotion-focused coping has been linked with poorer long-term psychological adjustment (Billings & Moos, 1984; Terry, 1991). Although this link with well-being may depend on the nature of the problem, where the source of the stress is intractable, individuals who prefer more problem-focused coping strategies may fare less well than those who prefer emotion-focused coping if tackling the problem has little effect and could result in feelings of powerlessness and frustration. Another distinction that has been made with respect to coping resources is between those that are internal (relating to personality) and those that are external (relating to social situations or organizational strategies).

In a review, Kinicki, McKee, and Wade (1996) found that both environmental and personality factors influenced choice of coping strategies, but that relationships between coping strategies and outcomes were inconsistent and that moderating effects were not always found. Cooper et al. (2001) noted that dispositional coping style was likely to moderate the influence of environmental factors (stressors) on outcomes (strain), whereas coping behaviors mediated the effect of stressors on strain (coping with high workload by working harder reduces strain associated with the initial demands). Harris (1991) suggested that the range of coping strategies available was to some extent determined by organizational values, culture, and norms. Organizational factors can influence both primary appraisal (the meaning of a particular encounter) and secondary appraisal (availability of coping resources). Ferguson and Cox (1997) classified the functions of coping strategies as: emotional regulation, approach, reappraisal, and avoidance. Both problem-focused and emotion-focused coping strategies can be effective depending on the situation and how an individual appraises it (Erera-Weatherley, 1996).

Much of the evidence related to injury involvement has highlighted negative effects of emotion-focused coping strategies. Using emotion-focused coping is likely to be less effective in many situations, leading to continued stress and increased injury vulnerability. There can also be long-term deleterious effects, both in terms of employee health and safety implications, where emotion-focused coping may lead to heavy drinking, smoking, or drug use. In their review, Stallones and Kraus (1993) estimated that for work injuries involving motorized vehicles, up to 27% involved a positive blood alcohol concentration, suggesting that excessive alcohol use played a significant role in approximately one in four work-related road fatalities (Stallones & Kraus, 1993). In relation to workplace injuries, Zwerling (1993) estimated that alcohol impairment was related to 10% of fatal injuries and 5% of nonfatal injuries. Although there is some evidence that cannabis use is associated with greater injury involvement (Crouch, Webb, Peterson, Buller, & Rollins, 1989), there is a lack of reliable empirical research on drug use and work injuries (Guppy & Marsden, 1996).

6.7 Stress interventions

Interventions designed to deal with occupational stress usually fall into three action types: primary, which eliminate, reduce, or alter stressors in the working situation; secondary, which are designed to prevent employees who are already showing signs of stress from becoming ill and to increase their coping capacity; and tertiary, which are treatment activities directed at employees showing strong stress reactions and rehabilitation after sickness absence (Cooper & Cartwright, 1994; Kompier, 1996). Kompier (1996) identified these possible types of prevention and intervention:

- *Primary (work environment)*: Changing job content, for example, job enrichment, employee participation, career development activities, team building, and social support
- *Secondary/tertiary (work environment)*: Directed at employees showing signs of stress, for example, special work schedules
- *Primary (individual/group)*: Selection, preemployment medical examination, health promotion, and wellness programs, for example, corporate fitness program
- *Secondary/tertiary (individual/group)*: Directed at individuals with serious stress-related problems, for example, rehabilitation, stress counseling, relaxation, and psychotherapy

The last of these categories, secondary and tertiary levels of intervention which are targeted at individuals, is most common (Kompier & Cooper, 1999). Jordan et al. (2003) found 70% of stress interventions to be focused at an individual level. For particular forms of stressful encounters (e.g., distress arising from pain in hospital settings), music has been found to be a stress-relieving mechanism (Chanda & Levitin, 2013; Hartling et al., 2013; Kwan & Seah, 2013).

6.7.1 Stress interventions and work outcomes

Secondary interventions include programs encouraging more healthy lifestyles (e.g., keep-fit centers on site, dietary advice, relaxation and exercise classes), and education on how to develop more effective stress management skills. Tertiary interventions act to mitigate an individual's stress symptoms; for example, by helping individuals to cope with their anxiety through relaxation and biofeedback. Positive effects of an improved lifestyle can feedback into the stress process by boosting individuals' stress resilience (i.e., resistance to stress-related illness). Secondary interventions operate by improving individuals' coping strategies and by replacing maladaptive coping styles with more successful ones, thereby making the workforce less vulnerable to stress. Such stress interventions should lower the risk of negative outcomes by increasing stress resilience; that is, a more stress resilient workforce should be less likely to experience stress symptoms, rather than by affecting their exposure to stressors. The combination of health protection and health promotion is a key aspect of the concept of "work health promotion" (WHP) programs, which are widely used within organizations.

In a review, Giga, Faragher, and Cooper (2003) found that the most widely used individual-level techniques were cognitive behavior therapy (CBT) and relaxation (each featuring in 30% of interventions); training and education were used in 15%–20% of interventions, while selection featured in only 1% of intervention programs. In their meta-analytic review, Richardson and Rothstein (2008) found that CBT was the most effective intervention for reducing negative psychological responses to stress, particularly anxiety (effect size 1.16). In a review of 17 meta-analyses and systematic reviews of intervention research, Goldgruber and Ahrens (2010) found that 91% of stress reduction interventions were effective; although relaxation techniques were used most frequently, the most effective interventions used cognitive behavioral methods. One explanation for the effectiveness of CBT is its proactive focus, as opposed to the more popular, but less effective (effect size 0.51) techniques of relaxation and meditation, which are essentially passive (Richardson & Rothstein, 2008). Interventions that focus on improving physical health have also been effective, as they enhance individuals' stress resilience. Conn, Hafdahl, Cooper, Brown, and Lusk (2009) found that workplace fitness interventions can increase the physical activity of employees, which can lead to improvements in both health and work-related outcomes. See Summary Text 6.6 for a description of CBT and a related therapy.

Organizational level interventions often focus on stressor reduction (primary action), for example, where the nature of the job could lead to stress, the task or the work environment might be subject to redesign; or, where the organization's structure or climate is the source of stress, structural changes or a new management style might be implemented. Such measures are most often considered in relation to changing the work environment, but may not always be practicable or desirable. For example, many jobs are characterized by high demands, where the nature of the demands cannot be changed. In these cases, the negative effects of high demands can be mitigated by the provision of job resources, such as job control, to create a challenging active job. Control may be increased through participation or increased autonomy. However, some organizational level interventions may involve secondary or tertiary action, where they are targeted at high risk groups or employees already experiencing stress symptoms, such as coworker support groups. Some aspects of the work environment may not be amenable to change, particularly certain aspects of the job itself, level of job security, or job-related pay and benefits; thus, it may be more appropriate to develop selection and recruitment procedures, first to ensure that appropriate individuals are attracted and selected for these posts, and second that appropriate support and training is offered to help post-holders. Cox et al. (2000) considered training to be primary prevention, rather than secondary, as it enhanced task-related knowledge and skills.

Literature on risk reduction at the primary level is limited, as few studies have focused on work redesign or restructuring (Giga et al., 2003; Israel, Baker, Goldenhar, Heaney, & Schurman, 1996). However, evidence suggests that primary interventions have a significant impact both on individuals' stress symptoms and on organizational outcomes,

SUMMARY TEXT 6.6 CBT and RET: A Brief Description

Cognitive behavioral therapy (CBT) was devised by Beck, Emery, and Greenberg (1985). The originators assumed that the root of depressed individuals' problems was illogical thinking. CBT techniques are based on the assumption that cognitive structures shape the way that people react and adapt to a variety of situations they encounter. While CBT is most used in treating depression, it is also used to treat anxiety. Beck et al. described the following three major cognitive patterns in depression (the *cognitive triad*):

1. A negative view of oneself
2. A negative interpretation of experience
3. A negative view of the future

People with these cognitive patterns are prone to react to situations by interpreting them in the light of the cognitive triad (Andreasen & Black, 2001).

For example, an unsuccessful applicant for a job that attracted many able candidates has his/her perception shaped by the stated cognitive triad, and may reason as follows: "I did not get the job because I am not really bright, despite my good college record, and the employer was able to figure that out" (negative view of self). "Trying to find a decent job is so hopeless that I might as well give up trying" (negative view of experience). "I am always going to be a failure; I will never succeed at anything" (negative view of the future). CBT techniques focus on teaching clients new ways to change their negative beliefs and assumptions about themselves, the world, and the future. As a treatment it tends to be relatively short term and highly structured. The major goal is to help people restructure their negative cognitions so that they view reality in a less distorted way and learn to react accordingly.

In contrast to rational emotional therapy (RET), CBT does not attempt to disprove ideas harbored by the depressed person. However, even though the specific techniques are different, the major goals of CBT and RET are similar—helping people to recognize and reject false assumptions that are key ingredients of their problems (Baron, 2002). Therapist and client work together to identify the client's assumptions, beliefs, and expectations, and to formulate ways of testing them. For example, the unsuccessful job applicant referred to above, states that s/he is a total failure. The therapist may then ask for a definition of failure, probing the extent of the perceived failure, and later explore areas of the client's life where success has been achieved. There is evidence to indicate that individuals learn to reinterpret negative events with outcomes that are encouraging (Bruder et al., 1997).

including productivity and absenteeism. Reviewing findings from 1500 projects funded by the Swedish Working Life Fund, Brulin and Nilsson (1994) found that productivity improved on average by 10%, including reduced production errors and delivery times. Kawakami, Araki, Kawashima, Masamuto, and Hayashi (1997) demonstrated significant effects on stress symptoms and absence levels following a 1-year intervention program involving changes to the work environment, job redesign, and training. Another means to reduce employees' stress levels has focused on improving communication. Cartwright, Cooper, and Whatmore (2000) found that improvements in communications within a UK government department led to significant enhancements in job satisfaction and perceptions of control. Evans, Johansson, and Rydstedt (1999) also found significant reductions in stress symptoms.

While interventions that focused on work design alone have been relatively uncommon, interventions combining changes to the work environment with increased participation have been increasingly employed by organizations (Giga et al., 2003). Evidence suggests that this combination is particularly powerful in terms of improving absence rates and performance (Bond & Bunce, 2001; Matrajit, 1992). For example, Terra (1995) reported a 50% decrease in sickness absence and improved productivity following the introduction of job redesign and self-regulating teams. Although outcome measures tend to emphasize productivity or sickness absence, Kvarnstrom (1996) demonstrated that a stress intervention involving participation, training, and job redesign resulted not only in significant reductions in turnover and absenteeism, and a major improvement in production, but also a significant decrease in workplace injuries. Changes to the level of skill discretion and authority over decisions have also been outcomes resulting from participation interventions (Theorell, Emdad, Arnetz, & Weingarten, 2001).

Increased job control may not be an appropriate means of reducing stress for all individuals. Although many will find that low control is a source of stress, there are individual differences in the degree of psychological strain experienced. This was supported by de Rijk, Le Blanc, Schaufeli, and de Jonge (1998), who reported a negative relationship between job autonomy and, both emotional exhaustion and health complaints only for those individuals with a high need for autonomy. The increased responsibility and decision latitude associated with greater autonomy can be perceived as an unwanted burden by some individuals, indicating that stress-reduction measures targeted at increasing employee autonomy will not suit all employees. Thus, employee participation and careful monitoring of the effects of any changes is needed when implementing stress reduction measures.

Sparks et al. (2001) recommended that relevant training support be provided; for example, where appropriate, problem-solving sessions could be held between supervisors and employees to identify job demands or stressors. Strategies could seek to increase employees' perceived control so that they can cope more effectively (Spector, 2000). Increasing social support can also be an effective means of boosting job resources, thereby buffering individuals against adverse effects of job demands. Establishing coworker support groups has been found to improve psychological well-being (Bagnara et al., 1999). Evaluating the effectiveness of support groups for health care professionals, Grossman and Silverstein (1993) found that employees reported reduced stress and improved performance at work. However, the groups experienced high dropout rates, perhaps because those employees who most needed help left the group.

Greater success was associated with groups with high autonomy and decision latitude, who perceived their work as more stimulating and received large amounts of supervisor feedback (Eriksson, Moser, Unden, & Orth-Gomer, 1992). Support groups have been successfully combined with individual-level techniques in stress interventions, such as CBT and relaxation; evaluation studies indicating that in addition to reducing stress symptoms, participants' support seeking skills and adequacy of coping improved (Elliot & Maples, 1991; Larsson, Setterlind, & Starrin, 1990; Lees & Ellis, 1990; McCue & Sachs, 1991). However, as with individual-level interventions, there is some doubt about long-term effects of group-level interventions. Nevertheless, in combination with primary organizational interventions, such as work redesign, training, and communication, long-term maintenance of low levels of stress has been reported (Griffin, Hart, & Wilson-Evered, 2000; Kalimo & Toppinen, 1999). For example, Kalimo and Toppinen (1999) examined work- and health-related factors over a 10-year period for 11,000 forestry industry workers who participated in a stress intervention program involving work redesign, training, and coworker support groups. The study found that a majority of staff rated their psychological working capacity as good and that stress remained low. Caution needs to be exercised with respect to the beneficial effects of social support, because social interaction (and even inappropriate counseling) may have detrimental effects upon an individual's health, for example, where conflict and strife is inherent in social relationships.

Although secondary and tertiary levels of stress intervention are effective when targeted at high risk individuals or groups, there has been a tendency for organizations to employ such programs for the whole workforce. This has been described as the inoculation approach to stress, as it focuses on the consequences, rather than the sources of stress, reflecting a view that stress is an inherent and enduring feature of any work environment. This approach can be very successful, particularly in the short-term, although there is some doubt about its long-term benefits. Isolated programs can have temporary effects in reducing stress (Murphy, 1988). Although stress symptoms may reduce as a result of treatment, and job perceptions become more positive, these changes have been found to decay over time if employees return to an unchanged work environment, with the same level of stressor exposure. There is also the danger that such programs tend to attract the worried well (Sutherland & Cooper, 1990), rather than those who most need help, particularly where programs are used across the workforce, rather than being targeted at high risk individuals.

Cox et al. (2000) and Jordan et al. (2003) recommended that a package of measures is more likely to succeed, particularly where measures are to be implemented at primary and secondary levels, and involve preventive measures in addition to tertiary remedies. Thus, to prevent and reduce stress symptoms, employers need to assess underlying causes of workplace stress. The importance of developing an intervention strategy based on a risk assessment of the health and safety hazards has been emphasized by a number of researchers (Clarke & Cooper, 2004; Cox et al., 2000; Giga et al., 2003). However, reviews of stress intervention programs (Burke, 1993; Cooper & Payne, 1988; Cox, 1993; International Labor Organization, 1992; Kahn & Byosiere, 1992; Karasek, 1992) have suggested that such programs have often failed to emphasize prevention at source.

Although still comparatively rare, examples of multiperspective approaches to stress intervention include measures aimed at both prevention and remedial action (Giga et al., 2003). Such approaches have a powerful effect, not only in making long-term improvements in mental and physical well-being (Elo, Leppanen, & Sillanpaa, 1998; Munz, Kohler, & Greenberg, 2001), but also in enhancing relationships, industrial relations, work climate, and increasing awareness of stress as an organizational issue (Lourijsen, Houtman, Kompier, & Grundemann, 1999; Nijhuis, Lendfers, de Jong, Janssen, & Ament, 1996; Poelmans, Compernolle, De Neve, Buelens, & Rombouts, 1999; Wynne & Rafferty, 1999). In addition, evaluation studies have reported significant reductions in sickness absenteeism (Lourijsen et al., 1999; Munz et al., 2001; Nijhuis et al., 1996; Poelmans et al., 1999), and mishaps and suicides (Adkins, Quick, & Moe, 2000), as well as improved productivity (Munz et al., 2001). Given the importance of feedback loops in the stress process, interventions that feed back to influence both the work environment and the person should be the most effective over time (Griffin & Clarke, 2011). This suggestion is supported by research showing that a comprehensive approach that includes interventions targeted at both the individual and the organization is most effective (Noblet & LaMontagne, 2006).

6.7.2 *Stress interventions and workplace safety*

Although the concept of WHP includes the impact on safety outcomes, little research has examined the effects of such programs on workplace safety. For example, Kvarnstrom (1996) found that a primary stress intervention (involving participation, training, and job redesign) led to a significant reduction in workplace injuries. Health promotion programs may influence safety outcomes in a number of ways, including demonstrating the organization's concern for employee well-being (which would generally improve safety climate), and improving employees' stress resilience, with a subsequent reduction in injury likelihood.

Hymel et al. (2011) argued that WHP programs should integrate the two approaches of health protection and health promotion such that: "health promotion interventions contribute dynamically to improved personal safety in addition to enhancing personal health, while occupational safety interventions contribute dynamically to improved personal health in addition to enhancing personal safety" (p. 695). Although integrated interventions are infrequently employed, initial reports indicated that they can be effective. For example, Caspi et al. (2013) implemented a multicomponent intervention program over 3 months across a number of hospitals; the intervention aimed to improve both health and safety outcomes (including safe patient handling and employee physical fitness) through unit-wide activities, supervisor involvement, and employee education. The authors found that general safety practices, as well as safe patient handling, and supervisor support improved significantly over the intervention period, but that there was no effect on physical fitness levels. Over a 3-month period the intervention was more effective in changing safety practices than employee health. The authors noted that the planned intervention for a physical fitness challenge was not implemented due to the difficulty of convening groups of health care workers on varying shifts. This may have contributed to the nonsignificant change in physical fitness during the intervention.

6.8 *Conclusions*

This chapter has discussed some of the mechanisms by which stress can influence injury involvement within organizations. Both acute and chronic stressors can significantly affect injury involvement, either directly affecting employees' behavior (e.g., via unsafe acts and safety behaviors) or indirectly via psychological and physical strain. However, Brief and George (1995) warned against conceptualizing the stress process as occurring at an individual level. While certain individuals may be identified as being high risk in terms of injury vulnerability, it is clear that stressors in the working environment present significant risks in terms of work injuries, as well as employee health and well-being. Any approach to stress intervention needs to focus both on identifying vulnerable individuals and addressing risk factors for the workforce as a whole (Clarke & Cooper, 2004). Sparks et al. (2001) pointed out that many research investigations and workplace interventions for employee well-being are conducted at managerial level, frequently excluding subordinate employees (Neck & Cooper, 2000; Worrall & Cooper, 1998). Yet, in terms of work-related injuries, these employees are usually on the front line, and most likely to suffer workplace injuries, although work-related injuries (e.g., as sustained in road traffic collisions) also affect managerial staff. However, because managers contribute to workplace injuries through inadequate decision making, perhaps as a result of work stress, injury involvement should not be considered as the only contribution to injury causation. However, these constitute latent conditions, rather than active failures, as the adverse effects of managerial actions are not always immediately apparent (Reason, 1997).

The tendency to view the stress process as necessarily bad should be balanced against the necessity of the stress experience. For example, Bandura (1989) contended that the experience of stress, which is aroused in the coping process over a period of time as a result of dealing with stressors, enhances the immune function; a position increasingly supported by resilience research. Moreover, as individual differences, including personality factors, play a part both in stress perception (being in the eye of the beholder) and in stress-related behaviors and conditions, including illness, not everyone suffers from work-related stress. However, while personality is generally considered to be a relatively immutable association of traits or characteristics (see Chapter 7), there is evidence that behaviors associated with personality characteristics that can affect the stress experience (e.g., Type A behavior) can be influenced to benefit the individual.

The notion of control is widely regarded as being central to individual stress management. This is with respect to perceived control over a set of circumstances (as in internal locus of control) or control over one's feelings about a situation (as in emotion-focused coping strategies), to hierarchical control (for example, for individuals with powerful organizational roles or who have high autonomy over their work and other aspects of their lives). Interventions aimed at increasing control, either perceived self-control or actual control, in terms of increased autonomy and decision latitude, have reduced stress levels.

Whilst a certain level of eustress is conducive to human functioning, high levels of stressors may be experienced as distress and require intervention. Most stress interventions are instigated by organizations with the intention of improving employee health outcomes, and, therefore, positively influence outcomes of commercial relevance, such as absenteeism, productivity, and compensation costs. However, such interventions are often fairly narrow in definition and conceptualized as health initiatives. Morrow and Crum (1998) noted that interventions such as bonus pay, sensitivity training for supervisors, or provision of on-site exercise facilities, tended to affect single outcomes, such as satisfaction with pay, supervision, or stress, respectively. Interventions that focused on safety improvements, particularly those aiming to change safety culture (see Chapter 10), are not only ethically appropriate, but are one of the few managerial interventions that appear to have widespread effect.

Research has highlighted the interaction between stress interventions, such as health promotion programs, and injury reduction (Mearns et al., 2003; Shannon et al., 1997). Positive benefits of health promotion programs (e.g., improved diet, increased exercise, weight loss, smoking cessation, acquiring stress-reduction techniques) have been demonstrated for employees' health (Demmer, 1995; Dugdill & Springett, 1994) as well as having favorable results for organizations; including reduced medical and disability costs, lower absenteeism and turnover rates, and enhanced corporate image (Conrad, 1988; Daley & Parfitt, 1996; Neck & Cooper, 2000). However, there is little recognition that such programs can be integrated into interventions aimed at improving safety (Clarke & Cooper, 2004).

chapter seven

Personality impacts

> A person is like some other people, all other people and no other person.
>
> **After Kluckholn and Murray (1953)**

In psychology, the individual is the prime focus of attention; the ways in which we are similar to, and differ from, other people and what makes each of us unique is a particular blend of measurable individual characteristics. If we can better understand the nature of these characteristics (or traits or dimensions) and link them with particular job requirements, then we should be better able to predict job performance, including safety requirements, and we might also be better able to select for, and tailor training toward, those individual characteristics. Thus, understanding relevant aspects of personality should help in managing workplace safety.

Evolution has equipped our species with a precious natural resource: diversity. This diversity enables, even requires us, to perceive risk differently, and to be predisposed to differential risk taking. Denying our diversity, or assuming that the same social and economic laws govern us all, would be to deny a vital aspect of our humanity. This diversity cannot be regulated for, nor can it be readily assessed in a general sense, although this chapter discusses many attempts to measure the diversity that exists between individuals and, more problematically, some of the ways that have been prescribed to address it.

Personality can be defined as those relatively stable and enduring features of an individual that distinguish each of us from other people, and that forms the basis of our predictions of other people's behavior (Pervin & John, 1999). For example, having consistently observed a person as being a safe driver, we may conclude that his/her personality encapsulates such a quality. Although psychology incorporates a number of approaches to personality, the dominant one focuses on traits.

Traits are dimensions of personality along which each individual is located. For example, we might describe one person as very outgoing, another as very reserved, and a third as somewhere in between. An individual's personality comprises the aggregate of their scores on each trait. A trait summarizes past behaviors and predicts future behaviors (Cook, 2004). Each of us possess a unique combination of traits (e.g., honesty, perseverance, assertiveness), which we share with others to a greater or lesser extent. Many psychologists now accept that five basic personality dimensions can be identified. While this is not a new notion (Fiske, 1949; Tupes & Christal, 1961), the labeling of these as the "Big Five" by McCrae and Costa (1985, 1987) spawned great interest and continuing debate, not least because of the considerable overlap of these with other approaches. The Big Five personality factors, as described by a number of writers (Barrick & Mount, 1991; Brand & Egan, 1989; Costa & McCrae, 1992a, 1992b; Costa, McCrae, & Dye, 1991; Deary & Matthews, 1993; Goldberg, 1992, 1993; Hendruks, 1997; McCrae & Costa, 1989) are:

1. Extraversion (vs. introversion)
2. Neuroticism (vs. emotional stability)

3. Openness to experience
4. Agreeableness
5. Conscientiousness

While there is some modest overlap between the five main dimensions, they are generally held to be distinct. More detailed lists of characteristics, derived from a number of studies, are in Summary Text 7.1. The five-factor model (FFM) of personality can assimilate other structures and is appropriate for organizing a range of traits that are useful as a description of normal personality, as well as in clinical practice (Costa & McCrae, 1992a). Dimensions similar to those identified in the FFM have been found in different cultures (Benet-Martínez & John, 1998, 2000; Benet-Martínez & Waller, 1997; Cheung et al., 1996), suggesting a possible biological foundation for at least some of these traits (Costa & McCrae, 1992a). This chapter focuses on personality and other individual differences—those characteristics that make us unique and that we share to some extent with other people and the influence that these have in terms of accident liability. After considering the concept of accident proneness and reviewing the role of personality traits in injury involvement, discussion turns to personality in the work environment, with particular emphasis on personnel selection.

SUMMARY TEXT 7.1 Facets of the Big Five Personality Dimensions

Extraversion (vs. introversion): Venturesome, assertive, energetic, spontaneous, talkative, frank, enthusiastic, uninhibited, sociable, outgoing, affiliative, socially confident, controlling (others), lacking emotional control, persuasive, warm, gregarious, active, excitement seeking, and positive emotions.

Neuroticism (vs. emotional stability): Neurotic, tense, apprehensive, defensive, highly strung, strong moods, vulnerable, oversensitive, labile, worrying, anxious, emotional, hostile, depressed, self-conscious, and impulsive.

Openness/intellect (or tender-minded vs. tough-minded): Affectionate, trusting, understanding, aesthetic, sensitive, feminine, imaginative, unusual, intellectual, tolerant, culture oriented, responsible, open, conceptual, innovative, change oriented, independent, behavioral, fantasy, feelings, actions, ideas, and values.

Autonomy (vs. agreeableness): Self-sufficiency, dominance, radicalism, will, independence, bohemianism, imagination, experimenting, rebelliousness, assertive, quarrelsome, detached, nontrusting, selfish, noncompliant, devious, and immodest.

Conscientiousness (vs. impulsiveness): Conforming, general inhibition, conventional, careful, self-controlled, orderly, compulsive, obsessive, productive, cognitively structured, striving to achieve, responsible, superego strength, plans ahead, persevering, disciplined, precise, industrious, detail conscious, competent, dutiful, self-disciplined, and deliberate.

Opposite lists would be applied to the other pole of each dimension (in parentheses).

Sources: Brand, C.R. and Egan, V., *Pers. Individ. Dif.*, 10(11), 1165, 1989.; McCrae, R.R. and Costa, P.T., *Am. Psychol.*, 44(2), 451, 1989.

7.1 Accident proneness

Of all the presumed personality traits, accident proneness, if it is a valid construct, is likely to be of greatest interest to safety and risk scientist practitioners. The concept of accident proneness initially developed from work by Greenwood and Woods (1919) in UK munitions factories during the First World War. They found that accidents were not distributed equally across workers, so that some workers had proportionately more than their "fair share" of injuries (i.e., the number of accidents expected by chance), although they drew no firm conclusions about possible reasons for this observed pattern. Later studies demonstrated that accident data consistently revealed that a small subgroup of people was involved in a disproportionately high number of accidents (Greenwood & Yule, 1920; Newbold, 1926). By correlating accident involvement over two successive time periods, these studies also demonstrated stability in individuals' accident records. This suggested that accident repeaters were not just "unlucky," but were consistently more likely to be accident-involved over time compared with nonaccident repeaters. Administering psychological tests, including personality tests, to both accident repeater and nonaccident repeater groups of drivers, Farmer and Chambers (1926) suggested that accident repeaters were "accident prone" and that accident proneness might be related to a stable personality characteristic. The term accident prone thereby entered the vocabulary, and was defined as a relatively permanent personal idiosyncrasy that predisposed individuals supposedly possessing it to a relatively high accident rate. What this meant was that certain durable personality characteristics associated with accident prone individuals supposedly caused them to have mishaps or injuries, regardless of environmental circumstances.

By accepting that some people are endowed with an accident prone personality, the next step would be to create a personality profile of accident repeaters, and establish traits that were common to all of them. Personality tests could then be used to screen out job applicants whose personality profile matched that of the typical accident prone person. However, in practice this approach has been elusive. Of the extensive research into accident proneness, most studies adopted either a statistical or a psychological approach (Shaw & Sichel, 1971), with a few references in medical and psychiatric journals to accident proneness as a personality disorder (Burnham, 2008).

The statistical approach fits accident data to theoretical distributions in order to test hypotheses regarding the nature of accident proneness, leading to debate and controversy (McKenna, 1983). Rigorous statistical testing of the accident proneness hypothesis shed doubt on its validity (e.g., Smeed, 1960). Hale and Hale (1972) argued that it was an artifact of inadequate control of confounding factors such as age, tenure, occupation, and risk exposure. Reason (1974) described accident repeaters as members of a club with an ever-changing membership, whereby new members joined and long-standing members ceased to qualify. It is possible that in some people accident proneness is a passing phase, while in others it is more enduring. Miner and Brewer (1983, p. 1004) described accident proneness as a transient personality maladjustment that particularly affected young people rather than a permanent trait, where, "the major motivation behind the repeated accidents themselves appears to be a desire to impress others by resorting to sudden and very risky decisions and behavior."

In her review of over 80 accident proneness studies, Porter (1988) pointed to the difficulty of using a statistical approach to study human characteristics that caused accidents, and reinforced Reason's contention that the accident prone group was a shifting one. This suggested that accident proneness was not an enduring individual trait. While some major life events seem to be associated with accidents (Legree, Heffner, Psotka, Medsker, & Martin, 2003), as the effects of these are likely to be temporary, it is difficult to establish measures on this basis. Those who are most vulnerable to stressors are most likely to be members of an accident prone group. The underlying personality factor may reflect attitude to life, that is, the way in which a person sees the world and adjusts in the light of their life experiences.

Approaches to the accident problem from the perspective of the individual that are exclusively concerned with personality tend to ignore underlying cognitive processes (e.g., related to coping), although less emotionally stable people are more liable to experience adverse impacts from stress (see Chapter 6). The best predictors of accident liability (i.e., a tendency to have accidents, independently of any personal ascription, such as accident proneness) according to Porter's (1988) study, appeared to be poor attention, and experience of recent major life events. This raises the issue of whether the concept of accident proneness is required at all, for if accidents can be explained by reference to such factors as attention and life events, then accident proneness as a hypothetical psychological construct is redundant and only has descriptive statistical value.

There are many problems with the concept of accident proneness from a psychological perspective. For example, whether it is a single personality trait or a number of different personality traits (Shaw & Sichel, 1971), or whether it is stable across situations, or over time (Adelstein, 1952; Guilford, 1973; Shaw & Sichel, 1971). In light of these, and other difficulties outlined previously, some researchers have concluded that it is not possible to isolate accident prone individuals, although others have maintained the validity of the accident proneness hypothesis. It can be readily acknowledged that certain people are more liable than others to have injuries. For example, in a study of over 7000 accidents, Mayer, Jones, and Laughery (1987) found that 3.4% of the workers in an oil manufacturing plant had 21.5% of the minor injuries and that many more workers suffered repeated minor injuries than would have been predicted by chance. Differences for major accidents (i.e., involving severe injuries) were less striking, but still significant. However, the authors noted that while this statistical phenomenon described the problem, it could not explain it. In a meta-analysis of studies of injuries requiring medical attention in the general population (published 1966–2005), Visser, Pijl, Stolk, Neeleman, and Rosmalen (2007) found that the distribution of accidents failed to match the pattern expected if they were distributed randomly (i.e., the Poisson distribution). This analysis supported the conclusion drawn by earlier studies that there is evidence of accident repeaters in the population, as a small number of individuals suffer injuries more often than would be expected by chance alone. Clarke (2011) concluded that there is consistent evidence that accidents are not random events evenly distributed across individuals, but that the statistical approach has yielded insufficient evidence to support any explanation for why this might be the case.

The psychological approach to investigating accident proneness has provided relatively little insight into possible psychological mechanisms that link personal characteristics and individual difference factors to accident involvement. The search for personal characteristics that might affect accident involvement has a long history, with various personality traits and individual differences being associated with accident repeaters. For example, high injury rates were found to be associated with low trust, low optimism, resentment, and negative employment attitudes (LeShan, 1952); high impulsiveness and risk-taking (Kunce, 1967); attention and motor function (Hakkinen, 1958); decision-making style (French, West, Elander, & Wilding, 1993) and Type A behavior (Nabi et al., 2005). In attempting to identify individual accident prone characteristics (in addition to personality traits), various tests have been administered, including those measuring psychomotor skills, visual skills, perception, attention, intelligence, life events, and stressor types. There is some evidence to support performance differences based on individual characteristics. Using the found experiment technique, Boyle (1980) showed that individuals were differentiated with respect to their injury rates, when controlling for ambient risk, risk exposure, age, and job experience. Boyle found a significant correlation between reported injuries in the first and second halves of the 8-year period over which records had been kept. Porter and Corlett (1989) found two distinct groups of individuals based on responses to their accident proneness questionnaire. These two groups were distinguished by their beliefs about their own accident proneness. One group (accident prone) believed that they were prone to everyday minor incidents (e.g., tripping, cutting, or bruising oneself, or breaking an object); the second group (nonaccident prone) believed that they were not prone to such incidents. Accident prone participants performed significantly worse on the primary task (a computer based unidimensional tracking task) of a dual task experiment. Such a performance deficit may be related to individual differences, but not necessarily to personality traits.

Given that many and varied characteristics have been associated with accident repeaters, a major problem with the accident proneness concept relates to the search for a single personality type. It is difficult to graft such a range of personal characteristics into a single personality type. Being unable to produce any overall stable profile of the accident prone person, it is not possible to use a reliable yardstick to establish whether someone has an accident prone personality.

Despite conceptual and empirical difficulties associated with accident proneness, this is not to say that the psychological approach should be abandoned. McKenna (1983) discussed barriers to the advancement of a psychological approach, including that the reliability of accident proneness over time restricts the extent to which psychological factors can account for a significant proportion of the variance (assuming that accident proneness is stable over time). For example, if the correlation for accidents across two successive time periods is .30, this restricts the variance that might be accounted for by psychological factors to <9%. However, research examining accident proneness in a sample of bus drivers found correlations over time of the order of .50, suggesting that psychological factors could account for up to 25% of the variance (af Wåhlberg & Dorn, 2009). For example, Beirness (1993) estimated that personality factors might account for 10%–20% of the variance in vehicle crashes. In addition to stable personal characteristics, such as personality traits, temporary psychological factors may also contribute to accident proneness in any specific period; for example, stress related to significant life events (Legree et al., 2003).

7.2 *Individual differences in error liability*

Investigation into accident causation has highlighted the role played by human error as a proximal cause (see Chapter 5), particularly cognitive ability and information processing (e.g., Arthur, Barrett, & Alexander, 1991; Avolio, Kroeck, & Panek, 1985; Groeneweg, 1992; Wagenaar & Groeneweg, 1987). The tendency toward errors (slips, lapses, mistakes) has been associated with road traffic collisions (Larson & Merritt, 1991; Parker, McDonald, Rabbitt, & Sutcliffe, 2000) and work injuries (Wallace & Vodanovich, 2003a, 2003b).

Accident research has demonstrated a consistently strong relationship between individual cognitive factors, errors, and accident involvement (e.g., Arthur et al., 1991; Avolio et al., 1985; Porter, 1988). One of the most common forms of error relates to attention, with attentional errors acting as a causal factor in up to 40% of road accidents (Brown, 1990), and up to 70% of rail accidents involving driver error (Edkins & Pollock, 1997). Porter (1988) reported that poor visual attention was most consistently related to accidents. In addition, Arthur, Strong, and Williamson (1994) found significant correlations between three versions of a computer-based visual attention test and self-reported accidents ($.26 < r < .38$). Attentional errors (e.g., lack of attention due to distraction off-task) occur more frequently when a behavior has become routinized (Reason, 1990). Individuals with low perceptual load are more likely to be distracted by irrelevant stimuli (Forster & Lavie, 2008), with greater distraction increasing accident likelihood. Thus, drivers with high perceptual load (e.g., negotiating heavy traffic) were less likely to be distracted than were those with low perceptual load (e.g., driving in free-flowing traffic).

Cognitive factors related to information processing have also featured strongly in the literature. For example, Arthur et al.'s (1991) meta-analysis found small to moderate effect sizes for cognitive and information-processing factors. Avolio et al. (1985) found associations between six measures of information processing and accidents ($.13 < r < .43$). Cognitive interpretation of information may also play a significant role. For example, examining collisions with highly conspicuous police vehicles parked on the hard shoulder of UK motorways, Langham, Hole, Edwards, and O'Neil (2002) found that collisions tended to occur due to vigilance failure and false hypotheses (e.g., drivers assuming that the vehicle was moving, not stationary), rather than sensory failure (e.g., drivers not seeing the vehicle).

Research has demonstrated that accidents often occur due to a lack of attention, memory lapses, and slips of action—collectively, cognitive failures. Broadbent, Cooper, Fitzgerald, and Parkes (1982) developed the Cognitive Failures Questionnaire (CFQ), which is a self-report measure of failures in perception, memory, and motor function. Based on the CFQ, Broadbent et al. (1982) reported evidence that liability for absentminded errors (e.g., opening the wrong door) is a feature of the psychological makeup of some individuals. It is not a measure of intelligence (being largely unrelated to IQ test performance), but reflects success at appropriately distributing attention, particularly under stress, and across multiple tasks (Larson, Alderton, Neideffer, & Underhill, 1997). A widely used instrument, the CFQ has excellent reliability and validity (Broadbent et al., 1982; Merckelbach, Muris, Nijman, & de Jong, 1996; Vom Hofe, Mainemarre, & Vannier, 1998). Although it was originally proposed that the CFQ has a single-factor structure, reflecting a general cognitive failure factor, later research suggested alternative two-, three-, or four-factor models. Rast, Zimprich, Van Boxtel, and Jolles (2009) found support for a three-factor model (comprising distractibility, forgetfulness, and false triggering), which demonstrated factor invariance across age groups (for participants aged from their early 20s to early 80s). While forgetfulness tended to increase with age, distractibility was relatively stable (until the early 60s, when it showed a significant drop). False triggering (interrupted processing of sequences of cognitive and motor actions) remained stable across age groups and was highly correlated with distractibility. This evidence supported a relatively enduring tendency for cognitive failures, which may reflect an individual's propensity to become accident involved (only forgetfulness tended to increase with age). High CFQ scorers tended to be involved in a relatively greater number of accidents, and to require more frequent hospitalization (Larson & Merritt, 1991; Larson et al., 1997). Based on a large-scale UK survey ($N = 7980$), of those reporting cognitive failures, 18% also reported minor injuries, and 7% also reported having had accidents at work (Simpson, Wadsworth, Moss, & Smith, 2005). Investigating the relationship between work injuries and vehicle crashes, and the propensity to commit cognitively based mistakes in 240 electrical workers, Wallace and Vodanovich (2003a) found that physical blunders (measured by the CFQ) predicted both work injuries and vehicle crashes.

Reported risk factors associated with cognitive failures include depression, anxiety, risk taking, general life stress, work stress, difficulty sleeping, general health, and neuroticism (Simpson et al., 2005). The relationship between individual proneness to cognitive failures (or error proneness) and increased vulnerability to stress has been well-established (Broadbent, Broadbent, & Jones, 1986; Reason, 1988). Exposure to work-related stressors may increase distractibility and so affect accident liability. For example, Elfering, Grebner, and Ebener (2015) found that workflow interruptions increased nurses' likelihood of near-accidents, this relationship being mediated by cognitive failures. In addition, exposure to stressors may result in strain, in turn affecting accident liability. For example, using information from Royal Navy databases, Day, Brasher, and Bridger (2012) found that effects of poor psychological well-being (high GHQ scores) on accident involvement were mediated by cognitive failures (high CFQ scores). However, Reason (1990) argued that it is not so much that stress induces a high cognitive failure rate, but rather that certain cognitive styles can lead to both absentmindedness (or lack of attention) and inappropriate matching of coping strategies to stressful situations. Reason and Mycielska (1982) considered that this was related to the amount of attentional capacity that people have available to deal with stress after other matters have been addressed. Such arguments would support an individual difference explanation to the effect that rather than cognitive failures being a product of temporary increases in general life or work-related stress, they reflect stable and enduring individual differences in the extent to which responses to stress influence accident involvement.

There is evidence to suggest that such individual differences may originate in dispositional factors, such as personality traits. Reason and Mycielska (1982) reported studies indicating a link between error proneness and the obsessionality personality trait (measured by the Middlesex Hospital Questionnaire—developed primarily to measure personality traits in clinical settings): the more obsessive an individual, the lower was their propensity to make errors. Wallace and Vodanovich (2003b) reported that conscientiousness moderated the relationship between cognitive failures and work injuries, such that the relationship between cognitive failures and injuries was stronger for low conscientiousness scorers. From a sample of nurses, Elfering et al. (2015) tested and supported a model in which the effects of conscientiousness on near-accidents were mediated by cognitive failures. These findings may suggest that personality influences both the tendency for cognitive failures, and also the extent to which failures can be recovered before they result in accidents or injuries.

7.3 Personality and accident involvement

A number of reviews have linked personality traits with accident involvement (e.g., Christian, Bradley, Wallace, & Burke, 2009; Clarke & Robertson, 2005; Hansen, 1988; Keehn, 1961; West, Elander, & French, 1991) and safety-related behavior (e.g., Beus, Dhanani, & McCord, 2015; Christian et al., 2009; Hogan & Foster, 2013). While Keehn (1961) concluded that extraversion and neuroticism were associated with higher injury liability, Hansen (1988) identified six personality characteristics that had some empirical support for an association with greater accidental injury involvement:

- External locus of control
- Extraversion
- Aggression
- Social maladjustment

- Neuroticism
- Impulsivity

Many studies examining the relationship between personality and injury involvement have focused upon vehicle crashes. Arthur et al.'s (1991) meta-analysis found small to moderate effect sizes for locus of control (0.20), and regard for authority (0.16). One difficulty with personality studies is that they have lacked a coherent taxonomy, resulting in a wide variety of personality traits being measured, using a mixture of different methods. Until the 1970s, studies typically used questionnaires (e.g., Katz Adjustment Scales), projective tests (e.g., Rorschach, TAT), and clinical interviews, while more recent studies have favored personality inventories, such as measures of the Big Five (e.g., NEO Personality Inventory, NEO-PI). Personality traits measured have included extraversion, neuroticism, social maladjustment, aggression, impulsivity, locus of control, Type A behavior, sensation seeking, and positive/negative affectivity. To clarify findings, Clarke and Robertson's (2005) comprehensive meta-analysis of the relationship between personality traits and accidents categorized a wide range of personality characteristics using the Big Five framework. They reported moderate effect sizes for both (low) conscientiousness ($\rho = 0.27$) and (low) agreeableness ($\rho = 0.26$), with higher accident involvement (including both work and traffic accidents). A significant association was found between neuroticism and work accidents ($\rho = 0.28$), and between extraversion and traffic accidents ($\rho = 0.24$). These findings were supported by Christian et al. (2009), who found that conscientiousness ($\rho = -0.26$), and neuroticism ($\rho = 0.19$), were related to occupational accidents and injuries. These authors also found a significant effect size for locus of control ($\rho = -0.26$). Including safety behavior (compliance and participation) in their meta-analysis, Christian et al. (2009) found that conscientiousness ($\rho = 0.18$), and locus of control ($\rho = 0.35$) were related to safety performance. Hogan and Foster's (2013) meta-analysis confirmed the role of conscientiousness as the strongest predictor of employees' safety behavior.

While personality does not directly predict road crashes, it can influence risky behavior through risk perceptions and risky driving engagement (Constantinou, Panayiotou, Konstantinou, Loutsiou-Ladd, & Kapardis, 2011; Elander, West, & French, 1993; Harbeck & Glendon, 2013; Ulleberg & Rundmo, 2003). Research has linked personality characteristics (e.g., sensation seeking, impulsivity) with risky driving engagement (Arnett, 1990, 1994; Dahlen, Martin, Ragan, & Kuhlman, 2005; Machin & Sankey, 2008; Schwebel, Severson, Ball, & Rizzo, 2006; Zuckerman, 1979b). Gray's (1987) reinforcement sensitivity theory (RST) relates both sensation seeking and impulsivity as motivational components. RST has been used as a conceptual basis to investigate driving behaviors (Brady, 2006; Castellà & Pèrez, 2004; Constantinou et al., 2011; Harbeck & Glendon, 2013; Ignjatović & Todorovski, 2010; Miller et al., 2009; Scott-Parker, Watson, King, & Hyde, 2012, 2013; Voigt et al., 2009). Two RST components regulate aversive and approach motivation. The aversive motivational system is the behavior inhibition system (BIS), also referred to as negative reactivity. Through sensitivity to signals of nonreward, punishment, and novelty (Carver & White, 1994; Gray, 1987; Torrubia, Àvila, Moltó, & Caseras, 2001), BIS inhibits behavior that could lead to painful or negative consequences (Smillie, Pickering, & Jackson, 2006). Thus, high BIS drivers may be more aware of traffic police and consequences of breaking the law if caught (e.g., fines, convictions), thereby increasing compliance with road rules, inhibiting risky driving behavior, and leading drivers to perceive higher risk in engaging in such behaviors.

The behavior approach system (BAS) has three subsystems: drive—enabling goal pursuit; reward responsiveness—encompassing openness to reward; and fun seeking—a desire for new and potentially rewarding experiences (Carver & White, 1994; Smillie et al., 2006; Voigt et al., 2009). Theorized to be sensitive to cues of reward and escape from punishment, BAS's main function is to initiate incentive-motivated, goal-directed behavior (Smillie et al., 2006), and it has been associated with traffic violations (Castellà & Pèrez, 2004; Constantinou et al., 2011; Scott-Parker et al., 2013). For example, high BAS drivers may be more likely to commit driving violations due to goal pursuit (e.g., needing to get somewhere quickly), through impulsive behaviors (e.g., tailgating), or to gain reward (e.g., establish autonomy). This system is theorized to activate the response to engage in the behavior and to decrease perceived risk.

These motivational systems predict individual differences in sensitivity to cues of reward and punishment, offering one possible explanation for why some individuals engage in risky driving behaviors. Empirical support was obtained for the contribution of personality and motivational systems to both risk perceptions, and reported engagement in ten risky driving behaviors (Harbeck & Glendon, 2013), who found that both negative reactivity (BIS), and BAS-fun seeking indirectly affected participants' reported engagement in risky driving behaviors, reflecting the mediating effect of perceived risk. Research testing aspects of RST with possible risk taking in work environments is awaited.

The following sections review evidence relating personality to safety outcomes (including occupational injuries), considering each of the Big Five personality dimensions in turn, including possible linking mechanisms.

7.3.1 Extraversion

Clarke and Robertson's (2005) meta-analysis revealed that while extraversion was not significantly related to occupational injuries, it was a valid and generalizable predictor of road traffic collisions. This finding reflected results from previous studies, which had suggested that extraversion was linked with road crash involvement (Arthur & Graziano, 1996; Fine, 1963; Smith & Kirkham, 1981), and Lajunen's (2001) large-scale analysis of data collected on traffic fatalities across 34 nations, which suggested that extraversion was associated with fatal vehicle crashes, but not with occupational injuries. However, in occupational settings, Beus et al. (2015) found that both extraversion and sensation seeking (a facet of extraversion) were significantly associated with safety-related behavior, which mediated the effect of personality on accident involvement. They found that sensation seeking had a stronger relationship than did overall extraversion, which was consistent with earlier findings (Beus et al., 2015).

The possible mechanism by which extraverts have higher injury liability is unclear. One explanation is that extraverts' lower level of vigilance means that they will be less involved in tasks and, therefore, be more liable to injuries (Eysenck, 1970). The finding that extraverts seek changes in self-stimulation to a far greater extent than introverts do and, therefore, demonstrate significantly poorer performance on vigilance tasks, has been largely validated (Koelega, 1992). In particular, evidence has supported a decrement in performance under monotonous conditions, such as highway driving, and that extraversion may mediate the relationship between fatigue and driving errors (Verwey & Zaidel, 2000). Another mechanism relating extraversion to crash involvement concerns sensation seeking. High sensation seekers have a greater tendency to take risks when driving, due to their increased need for novelty and thrills, and therefore, have higher crash liability (Jonah, 1997). Thiffault and Bergeron (2003) found that high sensation-seeking extraverts could be more sensitive to road monotony, and thus were more prone to fatigue-related driving errors.

Extraversion is a fairly broad personality category, which includes a number of lower level facets, including warmth, gregariousness, assertiveness, activity, excitement seeking, and positive emotions (Costa & McCrae, 1985). Some authors (Hough, 1992) have suggested that extraversion should be subdivided, for example, into affiliation (sociable, gregarious, outgoing), achievement (ambitious, confident, hardworking), and potency (forceful, optimistic, vital) facets. A number of lower-level facets have been investigated with regard to crash liability. Loo (1979) found that impulsiveness was related to risky driving, whereas sociability was not (both facets of extraversion). Studies examining sensation seeking have generally supported a relationship with crash involvement (Jonah, 1997).

Zuckerman (1994, p. 27) defined sensation seeking as, "the need for varied, novel, and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experiences." Sensation seeking comprises four components: thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility (Jonah, 1997; Zuckerman, 1990, 1994, 2004). Sensation seeking is generally measured through self-report forced choice questionnaires; for example, Zuckerman's sensation seeking scale (SSS) form V (Zuckerman, 1994), or the Arnett Inventory (Arnett, 1994). As a relatively stable aspect of personality, sensation seeking manifests itself in varied and novel behaviors throughout a person's lifetime, and sensation-seeking score is a partial predictor of risk-taking behaviors (Ball & Zuckerman, 1992; Zuckerman & Neeb, 1980). Zuckerman (1983) considered biological components of sensation seeking to be genetically determined. A genetic basis for sensation seeking has been suggested through a novelty gene associated with a dopamine receptor (Stuttaford, 1999). While not a direct measure of risk attitude, sensation seeking affects decision making in risky behaviors (De Brabander, Hellemans, Boone, & Gerits, 1996). Bradley and Wildman (2002), and Heino, van der Molen, and Wilde (1996) found that high SSS scoring individuals displayed more risk and reckless behaviors than did low SSS scorers.

Zuckerman (1983) reviewed evidence for neurological processes involved in personality, risk taking, and sensation seeking, while Zuckerman (1979) found that risk takers scored highly on extraversion and psychoticism. Of the association between arousal and risk-taking, Zuckerman (1983) found that fast alpha rhythms were often more pronounced in risk-seeking individuals. Thayer (1987) differentiated energetic arousal, which plays a role in information processing, and tense arousal, which is associated with threats. Evidence has indicated that danger and risk situations were associated with physiological arousal, and that people tried to optimize their arousal level (Trimpop, 1994).

The same risk-taking behavior can arise from different motivational states. For example, McMillan and Rachman (1988) characterized parachutists as either courageous, or overconfident, or fearless, based on different physiological responses to their first jump and in their behavior, which were attributed to different coping mechanisms and arousability. Arousal also depends upon the amount of skill required for a task (e.g., driving) and an individual's experience with that task. However, arousal alone is not sufficient to account for risk-taking behavior (Trimpop, 1994). Risk may be seen as a threat or a challenge or not perceived at all. Reviewing the evidence, Trimpop (1994) showed consistent correlations between sensation-seeking and risk-taking behavior.

In a review of 40 studies, Jonah (1997) found that a majority supported positive relationships between sensation seeking and risky driving ($.30 < r < .40$). Iversen and Rundmo (2002) concluded that risk-taking behavior was a major predictor of crash involvement, and that this behavior was associated with those who scored high on sensation seeking. This study contradicted earlier research suggesting that sensation seekers tended to drive fast, but also safely (Burns & Wilde, 1995; Clément & Jonah, 1984). Jonah (1997) found that drivers scoring high on the SSS rated the acceptability of risky driver behaviors as significantly higher and perceived lower risk than did drivers scoring low on the SSS on the same driver behaviors. Burns and Wilde (1995) found that high SSS drivers drove in a manner that was consistent with this aspect of their personality, and that SSS score provided a measure of prediction for road crash involvement. Arnett, Offer, and Fine (1997) also found that high SSS score drivers were involved in more road crashes than were sensation avoiders (low SSS score drivers). Furnham and Saipe (1993) found high sensation seeking to be the best predictor of risk-taking driver behaviors that led to road crashes and driving violations. Zuckerman and Neeb (1980) found a significant relationship between SSS and speeding for both males and females.

Although most focus has been on high levels of sensation seeking, examining the moderating effect of thrill and adventure seeking on the relationship between perceived risk and risky driving behavior, Hatfield, Fernandes, and Job (2014) found that high perceived risk acted as a deterrent for low scorers on thrill and adventure seeking (but had no effect on high scorers). This suggested that in promoting safe driving behavior, emphasizing the risk involved would probably only influence the behavior of those low in thrill and adventure seeking.

Matthews and Moran (1986) found that decision-making and risk-taking behaviors were more influential toward younger drivers' over-representation in road crashes, than were the age of the car, night-time driving, or alcohol consumption. Other researchers have found no difference between SSS and driving under the influence of alcohol (Jonah & Wilson, 1986; Mann et al., 1987; Vinglis, Stoduto, Macartney-Filgate, Liban, & McLellan, 1994). McMillen, Stoduto, Macartney-Filgate, Liban, and McLellan (1989) found greater risk taking in driving by high sensation seekers and that high sensation seekers took more risks when they believed that they had consumed alcohol. Low-sensation seekers became more cautious when they believed that they had consumed alcohol. When considering both speeding and tailgating violations, Yu and Williford (1993) found a relationship with SSS for drivers who were corrective service clients, while Jonah (1997), and West and Hall (1997) linked sensation seeking and risk taking in traffic with social deviance.

As noted before, there is an argument that sensation seeking (and therefore risk taking, violations, and crash involvement) is particularly associated with younger individuals, especially males. Begg and Langley (2001) found that as age increased, risk-taking behavior decreased, and studies comparing male and female drivers have generally found a higher prevalence of risk-taking driving behaviors among males (Begg & Langley, 2001; Clément & Jonah, 1984; Dobson, Brown, Ball, Powers, & McFadden, 1999; Groeger & Brown, 1989; Jonah, 1997; Jonah, Thiessen, & Au-Yeung, 2001). However, Ulleberg (2002) cautioned against treating young drivers as a homogeneous group, for example, in road safety campaigns, noting that the same personality characteristics may underlie both male and female risk taking. From a survey of 2498 novice Norwegian drivers, Ulleberg identified six clusters on the basis of self-reported risky driving behavior, two of which were deemed to be high risk in traffic. Over 80% of the first high-risk group were males, and were characterized by low altruism and low anxiety, together with high sensation seeking, irresponsibility, and driving-related aggression. The second high-risk group comprised nearly 60% females, who reported high sensation seeking, aggression, anxiety, and driving anger. Ulleberg concluded that specific combinations of personality traits were related to young drivers' risky driving and crash involvement. Personal characteristics of high-risk driver groups included high impulsiveness, sensation seeking, thrill seeking, hostility, driving-related aggression, personal problems, depression, anxiety, low altruism, poor emotional adjustment, irresponsibility, and rebelliousness.

In an observational study of over 2700 drivers on an Australian motorway (highway), Glendon and Sutton (2005) found that aside from the general finding that younger drivers were more likely than older drivers to be committing driving violations, virtually no other variable consistently predicted drivers' violating behavior. In a further study across three states, with a similar sample size, Glendon (2007) again found that males were more likely to be observed speeding, but that driver gender did not predict speeding. On the basis of their observed violating behaviors, Glendon and Sutton identified five driver groups, while Glendon identified four driver groups (see Summary Text 7.2).

Other facets of extraversion, such as experiencing positive emotions, have been found to *reduce* the likelihood of injury involvement. Iverson and Erwin (1997) found that positive affectivity (PA) was negatively correlated with work injuries. They suggested that the more socially adjusted aspects of extraversion, as reflected in PA, would mitigate against injury involvement, as high PA is associated with greater self-efficacy (George & Brief, 1992; Judge, 1993), which in turn is reflected in a higher degree of task engagement. They also suggested that high PA individuals had more accurate and systematic decision-making skills, such as requesting information, recognizing situational contingencies, and using data (Staw & Barsade, 1993), which is reflected in more thoughtful and careful appraisal of situations, thereby reducing their injury risk.

7.3.2 Neuroticism

Meta-analyses have suggested that emotional stability is associated with higher job proficiency across occupational groupings (Salgado, 2002). Conversely, it would be expected that neuroticism would be associated with lower job performance. According to Eysenck (1970), individuals high in neuroticism (characterized by anxiety, hostility, depression, self-consciousness, and impulsiveness) will be more injury involved. Indeed, neuroticism has been identified as a significant predictor of workplace accidents (Clarke & Robertson, 2005), and safety-related work behavior (Beus et al., 2015). The increased injury liability of high neuroticism individuals may be due to their distractibility, as they tend to be preoccupied with their own anxieties and worries, and are, therefore, more easily distracted from a task (Hansen, 1989; Iverson & Erwin, 1997). Neuroticism is associated with lower behavioral control, such that individuals high in neuroticism tend to demonstrate approach behavior in relation to threatening stimuli, and lower latency for disengaging from such stimuli (Derryberry, Reed, & Pilkenton-Taylor, 2003). Such behavior would mean that high neuroticism individuals tend to find themselves in more dangerous situations. Furthermore, such individuals tend to respond more negatively to threatening situations, and compared with low neuroticism individuals, were less likely to use proactive coping strategies (Bosma, Stansfeld, & Marmot, 1998; Parkes, 1990). This is consistent with Kaplan, Bradley, Luchman, and Haynes' (2009) meta-analysis, which found that negative affectivity (NA), similar to neuroticism, was significantly associated with occupational injury ($\rho = 0.20$). Further explanation for mechanisms linking neuroticism with injuries may be related to high neuroticism individuals' response to stress. Neuroticism has been found to be the strongest personality predictor of driver stress (Matthews, Dorn, & Glendon, 1991), suggesting that high neuroticism individuals may respond more negatively to environmental stressors.

Acute reactions to stressors, including anxiety and fatigue, decrease cognitive and performance capacities, such as reaction times and judgment, thereby increasing error likelihood (Steffy, Jones, Murphy, & Kunz, 1986). As well as reporting greater dissatisfaction and lower mental health, offshore oil workers who were high in neuroticism reported

SUMMARY TEXT 7.2 Driver Groups

Glendon and Sutton (2005) identified the five driver groups described as follows:

Group 1: *Nonviolating drivers*—Tended to be older and traveling with one adult passenger. The 44% of nonviolating drivers represents an upper limit of the size of this group. The true size of the nonviolating group of drivers is likely to be smaller than this, as at least some members would occasionally migrate into one or more of the violating groups.

Group 2: *Commercial violators*—Appeared as a fairly distinct group at around 10% of the sample, comprising mainly younger and intermediate age drivers of older commercial vehicles—trucks, utility vehicles, buses, and so on Their violations were mainly obstructed view, unsafe load, using cellular (mobile) phone, and polluting.

Group 3: *Tailgaters*—In nearly 55% of cases in which there was a lead vehicle, this was being tailgated. However, as in only just over 19% of cases was a vehicle following a lead vehicle at more than 2 seconds distance, it is possible that the potential tailgating (close following) driver group could be at least 80% of all drivers in this jurisdiction. A marked feature of this particular violation is that it is predicted by virtually no other variable, although solo drivers seemed to be slightly more prone to tailgate. As a broad driving cultural phenomenon (Zaidel, 1992), tailgating was found more or less equally among all age groups, both genders, and among drivers of all vehicle types and ages.

Group 4a: *Speedsters*—In this study, 38% of drivers were observed to be exceeding a signed speed limit, again indicating a widespread phenomenon, although one that could not be classified as a homogeneous violation—people speed for different reasons. Drivers in this group were more likely to be male and younger and were also much more likely to be driving newer private-use vehicles, particularly sedans—standard sized sedans were likely to be observed speeding at all rates over signed speed limits, while small sedans were more likely to be observed speeding up to 10% over the signed limit—reflecting the relative capacity of these vehicle types. While solo drivers were more likely to be observed exceeding the top speed limit—110 kph in this study, less intuitively, drivers with one or more children in their vehicle were more likely to be observed exceeding other speed limits. The respective risks selected by these subgroups might reflect, on the one hand, pressure upon professional drivers to reduce the amount of time spent traveling between appointments or between work and domestic locations. For drivers involved with childcare, their speeding behavior could reflect the urgency of transporting children to and from school, fitting such activity within an already full schedule, or other motivations. Various antecedents can generate the same observable behavior.

Group 4b: *Judicious speeders*—While a substantial proportion of speeding drivers were also observed violating in some other way, a small group—around 6% of all drivers, were separately identified on the basis that they were driving within 10% in excess of the signed speed limit but were not violating in any other way. In other respects they were similar to Group 4a. For drivers in this group it is possible that an implicit (sub)cultural driving behavior is that it is deemed acceptable to drive up to 10% over a signed speed limit. While cognitive states can only be inferred from a purely behavioral study, it might be that drivers in this group considered that they could safely drive within 10% above a signed speed limit, and were alert to the presence of police radar or speed cameras such that they could quickly reduce their speed to within the signed limit should this be necessary. Drivers in this group, while essentially law abiding, in the case of driving may make a reasoned case for accepting risks associated with exceeding the speed limit by a certain amount in order to obtain benefits of faster travel. As noted by Reason, Manstead, Stradling, Baxter, and Campbell (1990), risk–benefit trade-offs are among motivational factors likely to play a significant role in committing violations. Drivers in this group were most likely to be using their headlights, perhaps indicative on the one hand of a sense of urgency, and on the other as a safety feature.

Glendon's (2007) independent study emerged with similar findings, with four driver groups identified.

Group 1: *Nonviolating drivers*—Up to 40% of all drivers observed; mainly older drivers of both sexes, driving older vehicles.
Group 2: *Commercial violators*—Around 13% of drivers; tended to violate in ways other than speeding and tailgating.
Group 3: *Tailgaters*—At least 44% of all drivers of both sexes; tended to be younger.
Group 4: *Speeders*—At least 45% of all drivers of both sexes, tended to be younger, driving newer private-use vehicles with two or more passengers (including children when exceeding the highest speed limit observed).

Sources: Glendon, A.I., *Ergonomics*, 50(8), 1159, 2007; Glendon, A.I. and Sutton, D.C., Observing motorway driving violations, in Hennessey, D.A. and Wiesenthal, D.L. (Eds.), *Contemporary Issues in Road User Behavior and Traffic Safety*, Nova Science, New York, 2005, pp. 77–97.

significantly more work injuries than did their low-neuroticism peers. They were also more likely to be heavy drinkers when onshore (Sutherland & Cooper, 1991). While this may reflect high neuroticism individuals' tendency to experience greater stress symptoms, an alternative explanation is that these individuals have a generally negative world view, which leads them to negative perceptions of events, rather than actual experiences. There is, thus, a tendency for high neuroticism individuals to report more negative events, such as health complaints (Feldman, Cohen, Doyle, Skoner, & Gwaltney, 1999; Watson & Pennebaker, 1989), and workplace abuse (Wislar, Richman, Fendrich, & Flaherty, 2002), as well as injuries (Sutherland & Cooper, 1991). However, Clarke and Robertson (2005) argued that this tendency did not appear to account for the personality–injury association, as in their meta-analysis the significant relationship between neuroticism and injuries was found in relation to work injuries, in which most of the data referred to objectively verified injuries, rather than self-reports.

While high neuroticism individuals are more likely to experience emotions associated with anger and aggression, in combination with high agreeableness, it is likely that these individuals will be able to self-regulate their aggressive or angry responses to a situation. This would suggest that a combination of high neuroticism and low agreeableness increases the likelihood of an aggressive response (Ode, Robinson, & Wilkowski, 2008). Such individuals would be less able to control their negative emotional reactions to situations, thereby increasing their accident liability.

7.3.3 Conscientiousness

Conscientiousness includes a number of different aspects, including competence, order, dutifulness, achievement striving, self-discipline, and deliberation. Goldberg (1990) described the conscientious person as organized, conforming, detail conscious, and dependable. Meta-analyses have consistently reported a tendency for conscientiousness to correlate well across measures of job performance (Barrick & Mount, 1991; Salgado, 1997, 1998; Tett, Jackson, & Rothstein, 1991). However, it may not be desirable in all occupational fields, such as managerial performance (Robertson, Baron, Gibbons, MacIver, & Nyfield, 2000). There is evidence to suggest a role for conscientiousness in terms of safety performance, with empirical studies and meta-analyses supporting negative association between high conscientiousness and injuries (Arthur & Graziano, 1996; Cellar, Nelson, York, & Bauer, 2001; Christian et al., 2009; Clarke & Robertson, 2005; Wallace & Vodanovich, 2003b), and unsafe behavior (Beus et al., 2015; Christian et al., 2009; Hogan & Foster, 2013). Thus, low conscientiousness scorers have been found to be more likely to suffer workplace injury, and to engage in unsafe behaviors.

Low conscientiousness is characterized by a focus on satisfying immediate needs, regardless of future consequences for oneself or others (West, Elander, & French, 1993), little forward planning, a tendency to ignore rules and regulations (Arthur & Doverspike, 2001; Salgado, 2002), a lack of impulse control, which is related to higher levels of antisocial and risky behavior (Miller, Lynam, & Jones, 2008), and a failure to reflect upon on-task processes, such that cognitive failures were more likely to result in workplace accidents (Wallace & Vodanovich, 2003b).

There is evidence that several relevant personality traits, which relate to low scores on conscientiousness, are significantly associated with injury involvement. Low scores on self-discipline relate to carelessness and a lack of self-control (Shaw & Sichel, 1971; Suchman, 1970) and low scores on cautiousness to impulsivity (Mayer & Treat, 1977). A further aspect of conscientiousness, related to deliberation and order, is reflected in thoroughness in decision-making style; low thoroughness has been shown to correlate with crash risk (West et al., 1993). Low thoroughness is characterized by a lack of forward planning, absence of a logical or systematic approach to decision making, and inadequate cost-benefit analysis and contingency planning. A low score on the dutifulness facet relates to a lack of respect for authority and social order, comprising social maladjustment (Hansen, 1989), social rebellion and antagonism to authority (Shaw & Sichel, 1971), antisocial tendencies (Mayer & Treat, 1977), and social deviance (West et al., 1993). West et al. (1993) suggested that social deviance increased vehicle crash risk partly due to its association with increased driving speed. Two possible explanations were proposed: (1) exceeding speed limits involves breaking the law and individuals with higher social deviance have less regard for authority and (2) social deviance may be caused by a stronger focus on immediate needs (such as making good progress), irrespective of possible future consequences for oneself or others (e.g., the adverse consequences of a crash). The latter explanation is reflected in optimizing violations (Reason, Parker, & Free, 1994), which serve nonfunctional goals, such as joy of speed or aggression and become part of an individual's personal performance style. Individuals higher in social deviance (low conscientiousness) would be more likely to engage in this type of rule-related behavior.

There is consistent evidence that violations are associated with increased crash risk in motorists (Parker, West, Stradling, & Manstead, 1995) and truck drivers (Sullman, Meadows, & Pajo, 2002). Low conscientiousness individuals exhibit behaviors characterized by a focus on satisfying immediate needs, regardless of future consequences for self or others (West et al., 1993), a lack of goal setting and failure to follow rules and regulations (Arthur & Doverspike, 2001), and inadequate reflection relating to on-task processes (Wallace & Vodanovich, 2003b). Wallace and Vodanovich (2003b) also suggested that low conscientiousness individuals were more vulnerable to cognitive failures, which in turn predict workplace injuries. Wallace and Chen (2006) argued that conscientiousness influenced safe work behavior through motivational processes, such as self-regulation (Higgins, 1997). While the achievement striving aspects of conscientiousness are likely to lead to a promotion regulatory focus (e.g., concern for accomplishing a greater quantity of work more quickly), the dependability aspects of conscientiousness are liable to relate to a prevention regulatory focus (e.g., concern for adhering to work-related rules, responsibilities, and regulations). It has been found that the effect of conscientiousness on safe work behavior was fully mediated by self-regulatory processes, through both of these processes, but that the negative effect of a promotion focus was not sufficient to negate the positive effect of a prevention focus. Thus, high scorers on conscientiousness are likely to avoid accidents through maintaining a prevention regulatory focus, which emphasizes compliance with rules and procedures. However, as noted by Wallace and Chen (2006), compliance is only one element of safe behavior and does not equate to overall safe work performance. Christian et al. (2009) also found that conscientiousness was associated with safety performance (including both compliance and participation).

Much of the research on personality dimensions in relation to workplace injuries or vehicle crashes has been conducted on the assumption of linear relationships, for example, the more conscientious an individual, the less likely she/he is to be injured. However, some researchers have suggested that extremes of personality traits are related to crashes and injuries. Reason, Parker, and Lawton (1998, p. 300) suggested that, "mispliances are likely to be associated with the personal characteristics of rigid compliance ('rules must be obeyed at all times')." This suggested that while high conscientiousness would normally be associated with lower injury risk, extreme conscientiousness could have the opposite effect, as mispliances involve obeying rules, even where a procedure was not appropriate for the situation (incorrect action). The extent to which high conscientiousness is desirable will also depend on the requirements of the job: more highly routinized and formalized work will require reliable performance and safety compliance, and therefore, high conscientiousness. However, this personality characteristic may have lower importance in less formalized work.

7.3.4 Agreeableness

People who are high on agreeableness are pleasant, tolerant, tactful, helpful, not defensive, and generally easy to get along with (Hough, 1992). Some evidence has supported a negative relationship between agreeableness and injury involvement (Cellar et al., 2001); that is, more dominant, aggressive, and egocentric individuals (low scorers on agreeableness) are more likely to be injured. However, others have failed to support this association

(Arthur & Graziano, 1996). In their meta-analysis, Clarke and Robertson (2005) found that low agreeableness was associated with accident involvement, being a valid and generalizable predictor of both occupational injuries and vehicle crashes. Beus et al. (2015) found that low agreeableness was the strongest predictor of unsafe work behaviors (in relation to other personality traits), with certain subfacets of agreeableness (altruism, anger, impulsiveness) also being significantly associated with safety behavior.

Agreeableness includes elements of trust, compliance, and altruism, which are reflected in studies examining personality and injuries. Davids and Mahoney (1957) found a significant negative relationship between trust and injury involvement in workers at a U.S. process engineering plant. Studies measuring low altruism, egocentricity (Conger et al., 1959; Shaw, 1965), and selfishness (Shaw & Sichel, 1971), have all supported a significant positive relationship with injury experience. The opposite pole of compliance encompasses belligerence, hostility, and aggression, all of which have been examined in relation to injury involvement. Low agreeableness is associated with high emotional arousal and inadequate interpersonal strategies, such that individuals are less able to cooperate with others effectively and are more liable to respond aggressively to situations. Such characteristics have been associated with increased likelihood of antisocial and risky behavior (Miller et al., 2008). Mesken, Lajunen, and Summala (2002) suggested that interpersonal violations on the road (e.g., aggressive behaviors towards other road users) are associated with higher NA and emotional arousal, which in turn influence perception and information processing (Deffenbacher, Oetting, & Lynch, 1994), thereby increasing accident risk.

High aggression has been associated with greater accident involvement in railway workers (Sah, 1989), pilots (Conger et al., 1959), and bus drivers (Roy & Choudhary, 1985). Evidence has also suggested that high levels of aggression and hostility are associated with road vehicle crashes (Hemenway & Solnick, 1993; Norris, Matthews, & Riad, 2000; Suchman, 1970). A literature review concluded that hostile and aggressive tendencies were associated with greater injury liability (Beirness, 1993). The link between driver anger and subsequent near incidents on the road (Underwood, Chapman, Wright, & Crundall, 1999) suggested that drivers who become angry, and who responded aggressively, were more likely to crash. However, studies have generally found that violations (e.g., speeding) predicted crash involvement (Meadows, Stradling, & Lawson, 1998; Parker, West et al., 1995), rather than aggressive behavior (e.g., expressing hostility to another road user) (Sullman et al., 2002).

Dahlen et al. (2005) found that driver anger was a major predictor of risky and aggressive driving, with verbal and physical aggression, and use of vehicle to express anger accounting for 6%–25% of the variance. To a lesser extent, driver anger was also associated with minor loss of control, lapse of concentration, and close calls. But other personality traits accounted for additional variance (including sensation-seeking, impulsiveness, and boredom proneness). Aggressive driving substantially increases the risk of road accidents, and may be involved in up to one third of all road accidents (Dahlen, Edwards, Tubré, Zyphur, & Warren, 2012). Using structural equation modeling, these authors found that driver anger and low agreeableness were significant predictors of aggressive driving, which in turn predicted driving performance (crashes & moving violations). Other personality factors, extraversion, emotional stability, openness and conscientiousness, were not significant predictors. Driver anger and low agreeableness accounted for 36% of variance in aggressive driving (and 7% variance in driving performance). Drivers who were low in agreeableness were intolerant of others, uncooperative, inflexible, and not concerned with being courteous. As such a disposition may make an individual more likely to act on feelings of anger, low agreeableness and driver anger together increased the likelihood of aggressive driving.

The relationship between anger/hostility and accident involvement may provide an explanation for the association with the personality trait of Type A Behavior Pattern (TABP). TABP is characterized as displaying very high levels of concentration and alertness, achievement striving, competitiveness, time urgency and aggressiveness on the one hand, and irritability, hostility, and anger, on the other (Friedman & Rosenman, 1974). Two questionnaire measures, the Jenkins Activity Survey (Jenkins, Zyzanski, & Rosenman, 1971) and the Bortner Rating Scale (Bortner, 1969) have been developed to determine associations between TABP and crash involvement. Perry (1986) found significant correlations between scores on the Jenkins Activity Survey and number of crashes (.29), and violations (0.35), and a questionnaire measure of driving impatience in a sample of 54 students. However, no account was taken of risk exposure, age, or sex. A study of bus drivers in the United States and India using the Bortner Rating Scale (Evans, Palsane, & Carrere, 1987) found that drivers characterized as Type A in both countries had higher crash rates than did those characterized as Type B, and that for an Indian sample TABP was associated with more frequent braking, passing, and sounding the horn. Sutherland and Cooper (1991) found that TABP was associated with significantly more work injuries, greater job dissatisfaction, poorer levels of psychological well-being, and higher subjective stress.

It is possible that greater crash involvement is associated with TABP in individuals who display anger/hostility, as they are more likely to express aggression; general anger is predictive of anger as a response to impeded progress on the road, which is predictive of an aggressive response (Lajunen & Parker, 2001). TABP would be related to crashes due to increased propensity for violations, such as speeding. This is supported by West et al. (1993), who found that TABP predicted driving speed, and by Perry (1986), who found a significant relationship between TABP and violations. However, because much of the research relating to TABP is conducted within a road traffic environment, more research is needed to determine whether these findings can be replicated within a work context. The TABP concept has also been criticized. It has been suggested that it may cover two or more underlying dimensions, which are canvassed to differing degrees by different measures; the Bortner scale, for example, appears to factor into one dimension of competitiveness and one of speed (Edwards, Baglioni, & Cooper, 1990).

Meta-analyses predicting job performance have demonstrated mixed findings for agreeableness, with Barrick and Mount (1991) finding little effect, but Tett et al. (1991) finding a positive relationship ($\rho = 0.22$). However, agreeableness is most salient in situations that involve interaction or cooperation with others (Barrick & Mount, 1991). The common element, in both occupational and nonoccupational settings, may relate to the decreased capacity of low scorers on agreeableness to manage interpersonal relations (Clarke & Robertson, 2005). Mount, Barrick, and Stewart (1998) found that agreeableness was related to job performance in occupations involving interpersonal relations, particularly in team-based working. Individuals who are low in agreeableness may be less able to cooperate with others effectively and be more liable to respond aggressively to situations, thereby increasing their injury liability. On the road, individuals low in agreeableness may be more prone to interpersonal violations (e.g., aggressive behaviors toward another road user) (Mesken et al., 2002). Examining group processes and work injuries, Hofmann and Stetzer (1996) suggested that establishing group norms for safety-related behaviors, such as approaching team members engaged in unsafe acts, could have a significant impact on injury involvement. High agreeableness individuals, who perform more effectively in groups, may be more amenable to developing such group norms and be more responsive in applying group norms to their own behavior. This suggests that teams with a high proportion of highly agreeable individuals could be particularly effective in terms of safety-related outcomes.

7.3.5 Openness

Openness has been the least studied of the Big Five personality dimensions in terms of job performance. Likewise, compared with the other personality dimensions, fewer studies focus on openness and injury involvement. Arthur and Graziano (1996) found little evidence of a relationship between openness and self-reported vehicle crashes; however, other studies have examined some facets of openness. High openness scorers are imaginative, unconventional, curious, broadminded, and cultured. Suhr (1961) found a negative relationship between imagination and injuries, while a positive relationship was found by Lardent (1991). Positive relationships have been supported between artistic, literary, and aesthetic interests and injuries (Conger et al., 1957; Parker, 1953). Meta-analyses (Barrick & Mount, 1991; Salgado, 1997) have supported a relationship between openness and training proficiency, indicating that high openness is associated with a positive disposition toward learning. Thus, high openness would be desirable for developing a well-trained workforce. However, particularly in routinized working environments, where safety compliance may be critical, more imaginative, curious, and unconventional individuals could be more liable to rule violations, experimentation, and improvisation; whilst low scorers on openness would have an enhanced ability to focus on the task in hand and might, therefore, be less likely to have injuries. However, there is little evidence to support a substantive relationship between openness and injury involvement either one way or the other (Clarke & Robertson, 2005). Beus et al. (2015) also found no evidence of an association between openness and unsafe work behavior.

7.4 Core self-evaluation and safety outcomes

Core self-evaluation (CSE) reflects an individual's overall perception of self-worth and comprises self-esteem, generalized self-efficacy, locus of control (LoC) and neuroticism (Judge, Martocchio, & Thoresen, 1997). These characteristics reflect an evaluation of one's own self-worth and are fundamental to a person's self-concept. Johnson, Rosen, and Levy (2008) suggested that CSE traits relate to individuals' beliefs about their self-regulatory and behavioral capacities; for example, their ability to cope with a range of situations, their ability to influence the environment successfully, and their ability to remain calm and demonstrate low reactivity in everyday situations. Given the nature of these characteristics, Clarke (2011) argued that CSE is likely to affect employees' accident liability, such that those who score higher on CSE are better able to cope with the demands of the work environment, and are less likely to place themselves in situations with an increased risk of injury. CSE has been found to have a significant effect on job satisfaction and job performance (Judge, Erez, Bono, & Thoresen, 2003). Although it has not been examined in relation to work-related or other types of accidents, CSE is likely to affect individuals' accident involvement as it reflects their beliefs in the controllability of the environment and their perceived ability to successfully effect change in that environment (Clarke, 2011). Empirical evidence has supported a link between the different components of CSE and accidents. Associations have also been found between CSE and safety-related behavior, such that high CSE is associated with greater safety compliance and safety participation (Yuan, Li, & Lin, 2014).

Given its strong emotional rather than cognitive nature, it has been argued that neuroticism is the most fundamental element within CSE (Johnson et al., 2008), and empirical findings have supported an association between neuroticism and accidents. Given their propensity for error-proneness and distractibility, high neuroticism individuals are more likely to be involved in accidents (Hansen, 1989; Iverson & Erwin, 1997). Added to this is their tendency to demonstrate approach behavior in relation to threatening stimuli, a low latency for disengaging from such stimuli (Derryberry et al., 2003), and general failure to seek active control of the environment (Judge, 1993). Further discussion on the role of neuroticism in accident involvement is in Section 7.3.2.

Self-esteem is an individual's appraisal of their own self-worth, while self-efficacy is an estimate by the individual of their ability to perform and cope successfully with situations. Although conceptually distinct, these two constructs may be difficult to separate in practice (Judge, Locke, Durham, & Kluger, 1998). Individuals with low self-esteem tend to perform at lower levels; they tend to react strongly to situations, but cope with them passively. Such tendencies may lead individuals to be more accident-involved; indeed, Norris et al. (2000) found that lower self-esteem was significantly associated with more road traffic collisions, similar to a finding reported by Smith and Heckert (1998). In a sample of young male drivers, Vavrik (1997) found a significant relationship between high self-esteem and crashes; the author suggested that male adolescents may use risky driving as a way of showing off and increasing self-esteem, which increased their accident risk.

Generalized self-efficacy reflects individuals' assessment of their capability to perform certain tasks and enhances feelings of control. A significant relationship between self-efficacy and accidents has also been reported (Cellar, Yorke, Nelson, & Carroll, 2004). This may relate to the potential role of perceived control in relation to occupational safety. Perceived control over safety (i.e., an individual's belief that s/he is knowledgeable about safety and is capable of controlling his/her safety behavior) correlated with self-reported occupational injuries (Ho, Smith, & Chen, 2006; Huang, Chen, Krauss, & Rogers, 2004). However, other studies have failed to demonstrate any correlation between perceived control over hazards and occupational injuries (Leiter, Zanaletti, & Argentero, 2009).

An internal LoC is associated with the belief that outcomes can be controlled; such that internals possess a greater need for self-determination and competence than externals do (Ng, Sorensen, & Eby, 2006). LoC is related to intrinsic motivation to dedicate effort to activities, with higher levels of motivation leading to better task performance (Judge & Bono, 2001). Internals are more likely to adopt a proactive approach to managing safety issues in the workplace and so have a reduced vulnerability to accident involvement. In contrast, individuals with an external LoC are more likely to believe that injuries happen due to forces outside their control and subsequently are less likely to take personal responsibility for safety, or to take precautions to prevent injuries occurring. Furthermore, externals are less likely to prevent the development of stressful conditions and to be less proactive in the face of negative situations, making them more vulnerable to the negative effects of stress. Externals take more risks in the workplace (Salminen & Klen, 1994), engage in higher levels of unsafe work behavior (Christian et al., 2009; Kuo & Tsaur, 2004), and are more accident involved (Janicak, 1996; Jones & Wuebker, 1993). That an external LoC would be related to injuries is supported by meta-analytic findings that external LoC has a small to moderate effect for road traffic accidents (Arthur et al., 1991). In a meta-analysis, Christian et al. (2009) found that LoC had a moderate effect ($\rho = 0.35$) with safety performance at work. This effect was stronger for safety participation than for safety compliance, suggesting that an internal LoC is particularly associated with participation in safety-related activities and speaking up about safety, reflecting the belief that engaging in such activities will affect the level of safety in the workplace. Given that an internal LoC is related to enhanced motivation and task performance (Ng et al., 2006), this would be consistent with the behavior of internals and also research that has linked LoC with citizenship behavior (Blau, 1993).

Neal and Griffin (2006) found that motivation led to increased safety participation, which in turn further increased motivation, leading to a positive gain spiral. Given its association with proactive behavior (e.g., showing initiative in developing new ideas and solving problems), self-efficacy may also be associated with safety participation, (Parker, Lawrie, & Hudson, 2006), and suggesting improvements (Axtell et al., 2000). Ng et al. (2006) argued that LoC is related to attitudinal and behavioral outcomes at work through self-evaluation of well-being, internal motivation, and a cognitive orientation of maintaining active behavioral control. Positive self-evaluations are likely to be reflected in general well-being and affective reactions (e.g., job satisfaction). This suggests a further mechanism through which CSE may influence safety behavior and accident liability, as both job satisfaction and general well-being are associated with accidents (Clarke, 2010). Therefore, CSE may act as a protective factor in relation to accident involvement as it leads to better general well-being and job satisfaction, greater motivation, and the tendency to take active control of the environment, including through safety participation. Evidence of the protective effect of CSE came from Yuan et al. (2014), who found that CSE moderated the relationship between stressors and safety-related behavior.

7.5 Behaviors linking personality with safety outcomes

Much of the research examining the influence of personality on safety outcomes has focused on identifying associations, with less emphasis on psychological and behavioral mechanisms that underlie these relationships. Research has also tended to focus on the role of personality in terms of distinct dimensions (e.g., the Big Five, as reflected in the previous sections), rather than interactions between personality dimensions. Hogan and Foster's (2013) meta-analysis found that a composite of multiple personality traits was more predictive of safety behavior than any of the separate dimensions alone on supervisory ratings of safety-related behaviors. For example, in combination with low neuroticism and high conscientiousness, high extraversion scorers experienced lower levels of psychological strain (Grant & Langan-Fox, 2006), which reduced error-proneness and accident liability.

Hogan and Foster (2013) further demonstrated that different combinations of personality traits would be more or less important for safety depending on the behavioral outcome, including complying with rules, remaining vigilant, risk taking, and managing stress. Conscientiousness has been strongly associated with safety outcomes as safety in many settings depends on following rules and regulations, and failing to follow rules leads to an increase in the risk of accidents and injury. However, a personality composite that included agreeableness (in addition to conscientiousness) would be more predictive, as agreeableness has also been associated with following rules (Salgado, 2002). Other personality traits, which are facets of the Big Five, have been strongly associated with safety outcomes. For example, sensation-seeking with risk-taking behavior, and boredom proneness with remaining vigilant (see Section 7.3.1). Occupation type is likely to influence which personality traits are most likely to impact safety outcomes, as behavioral requirements differ between jobs (e.g., remaining vigilant is likely to be more important for air traffic controllers than for paramedics). Different jobs have different safety characteristics, requiring distinct skills and abilities. For example, where vigilance is required, errors may be most likely to result in injuries. However, a well-defended system is most at risk from violation of safe working practices (Lawton & Parker, 1998), suggesting that individual differences are important in determining how individuals perform in varying work environments.

Sherry (1991) suggested that a poor person–environment (PE) fit is related to injuries. Poor PE fit is likely to affect an individual's behavior directly, and also indirectly, as greater stress can increase injury likelihood (see Chapter 6). The wider context may also determine which personality traits are most influential on behavior (Clarke & Robertson, 2005; Lajunen, 2001). For example, Clarke and Robertson (2005) found that extraversion was related to road traffic safety (but not to occupational safety), but that the opposite was found for neuroticism. These findings suggested that different behaviors are required in different contexts, which accounted for the differential influence of personality traits on safety outcomes. It has been argued that individual differences are less influential in occupational settings as work environments are often more restrictive in terms of allowable behavior (James, Demaree, Mulaik, & Ladd, 1992).

Within organizational contexts, differences may be based on organizational level, although most studies have focused on "front-line" employees, rather than managerial employees. Managers have considerable potential to influence organizational safety, even though their job role means that they are less likely to be injured in occupational accidents. Wagenaar (1992) suggested that while operators run risks, it is those higher in organizational hierarchies (i.e., managers) who consciously take risks. However, even at this level, the literature concerning managers' risky decision making has suggested that habitual behavior is a significant factor. Both inertia (habitual response to risk) and outcome history are significantly related to risk propensity (Pablo, 1997; Sitkin & Weingart, 1995). More experienced decision makers may focus on their past ability to cope with obstacles, raising their level of confidence, and increasing the likelihood of risky behavior. However, less experienced individuals may also have raised levels of confidence because of their lack of knowledge of the possible consequences of their actions (also leading to riskier behavior). Evidence has also suggested that organizational factors (e.g., industry sector, degree of governmental control) directly affect risk propensity (Williams & Narendran, 1999).

An organization's culture will influence managerial decision making, dependent on the cultural value attached to risk seeking—either uncertainty or risk avoidance (certainty). The risk climate within which managers operate provides a frame of reference for behavior and indicates the acceptability of risky behavior. Managers' personality traits also have important influences on their leadership style and job performance. There is evidence that personality affects managerial performance, which may have implications for safety. Resick, Whitman, Weingarden, and Hiller (2009) showed that CEO personality (CSE) was strongly related to leadership style, which in turn was associated with organizational performance. In a meta-analysis of dark triad of personality with work behavior, O'Boyle, Forsyth, Banks, and McDaniel (2012) found negative effects of Machiavellianism ($\rho = -0.07$), and psychopathy ($\rho = -0.10$) on job performance, and positive effects of Machiavellianism ($\rho = 0.25$), narcissism ($\rho = 0.43$), and psychopathy ($\rho = 0.07$) on counterproductive work behaviors.

In terms of managing stress, high neuroticism individuals may be more vulnerable to accidents due to their tendency to respond negatively to threatening situations, and use less proactive coping strategies. In contrast, those high in extraversion and conscientiousness are more likely to view potential stressors as a challenge and to adopt problem-solving coping strategies (Watson & Hubbard, 1996). Grant and Langan-Fox (2006) showed that the effect of high neuroticism in combination with high conscientiousness led to higher stress exposure. However, the combination of high neuroticism/low conscientiousness was likely to lead to higher accident liability, as this combination is most associated with the use of maladaptive coping strategies (Grant & Langan-Fox, 2006). A failure to cope with stressors is likely to lead to higher strain, which can result in more procedural violations (e.g., noncompliance with safe work practices) and higher error propensity (Fogarty & McKeon, 2006).

7.6 Individual differences and job stress

Individual differences, including personality traits, influence safety outcomes through their effects on safety-related behaviors (Christian et al., 2009; Hogan & Foster, 2013), and also by acting as a moderator between other antecedents and safety outcomes (e.g., Wallace & Vodanovich, 2003b; Yuan et al., 2014). Personality traits can also influence safety through moderating the stress–strain relationship, as exposure to stressors can increase accident liability. Individual differences that have been supported as moderators of the stress–strain relationship include LoC, neuroticism, self-efficacy, and self-esteem (Cooper, Dewe, & O'Driscoll, 2001; Spector & O'Connell, 1994), NA/PA (Näswall, Sverke, & Hellgren, 2005), Type A personality (Day & Jreige, 2002), hardiness (Beehr & Bowling, 2005), proactive personality (Parker & Sprigg, 1999), and optimism (Totterdell, Wood, & Wall, 2006).

Bolger and Zuckerman (1995) suggested that personality may play an important role in the stress process by influencing individuals' exposure to stressful events (differential exposure), which then leads to strain (see Figure 7.1). People with different personalities seek out different types of jobs; for example, Sutherland and Cooper (1991) found a high proportion of extraverts working on drilling rigs (the most hazardous area on offshore oil platforms), and Farmer (1984) found that a sample of pilots were more aggressive and dominant than the norm. An alternative view is the differential reactivity hypothesis, which maintains that certain dispositional variables may moderate the impact of job stressors on outcomes. There are several mechanisms by which personality may moderate the effects of stress, including the effect that personality has on individuals' appraisals of situations (Cohen & Edwards, 1989), and their choice of coping strategies (see Figure 7.2). Individuals respond to stress in different ways depending on their personality, leading to a further effect via coping strategies, which also moderate the relationship between stress and injuries. See Summary Text 7.3 for the possible effects of negative affectivity.

Buffering effects have been supported for each of the elements of core self-evaluations (CSE), that is, neuroticism, self-efficacy, self-esteem, and LoC. Studies focusing on CSE as an integrative construct have found that individuals with high CSE tended to perceive stressors as less threatening, experienced less strain, and used less maladaptive coping mechanisms than did those with low CSE (Kammeyer-Mueller, Judge, & Scott, 2009). Furthermore, neuroticism played an important buffering role in the stress–strain relationship. Many of

Figure 7.1 The effects of personality on injuries mediated by stress.

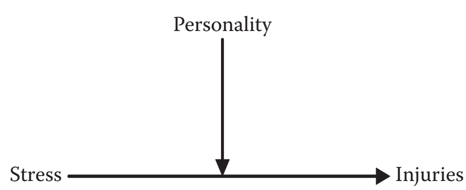


Figure 7.2 The effects of stress on injuries moderated by personality.

SUMMARY TEXT 7.3 Possible Effects of Negative Affectivity (NA) on the Stressor–Strain Relationship

Symptom perception—NA directly affects perceptions of stressors (high NA individuals have a negative world view). High-NA individuals were found to report significantly higher levels of eight out of nine stressors, higher job dissatisfaction, and poorer levels of mental health (Sutherland & Cooper, 1991).

Hyperresponsivity—NA is more sensitive to the impact of stressors, therefore NA has a direct effect on strain. Neuroticism was the strongest single predictor of driver stress (Matthews et al., 1991), suggesting that high neuroticism individuals may respond more negatively to the presence of stressors, increasing their vulnerability to vehicle crashes.

Differential selection—High-NA individuals are more likely to be found in jobs that are stressful (low autonomy and job scope). Sutherland and Cooper (1991) expected that high-NA individuals would prefer a nonstimulating environment, and would be employed on the production platform, rather than drilling; however, significantly more high-NA individuals were found on drilling rigs (a more stressful work environment).

Stress creation—Behavior of high-NA individuals gives rise to stress, particularly by creating conflict and a difficult social environment.

Transitory mood—NA is an outcome of mood, affected by job conditions.

Causality—Consistent exposure to stress induces high NA.

Source: Spector, P.E. et al., *J. Organ. Behav.*, 21(1), 79, 2000.

the personality traits that have been found to buffer the negative effects of stressors and reduce strain emphasize personal control over the environment. A number of studies have found three-way interactions between job demands, job control, and personality traits, such that those with control-oriented personalities are better able to manage in situations of high demand and high control. Three-way interactions have been supported for self-efficacy (Schaubroeck & Merritt, 1997), proactive personality (Cunningham & De La Rosa, 2008), and LoC (Meier, Semmer, Elfering, & Jacobshagen, 2008), demonstrating that those able to effectively exercise job control (e.g., due to internal LoC) have better psychological well-being and lower strain. Those with less control-oriented personalities (e.g., external LoC) find high job control to be a stressor (Meier et al., 2008). Similar three-way interactions have been demonstrated in relation to other job resources, such as social support. Individuals with high self-efficacy tend to view social support positively, whereas those with low self-efficacy tend to view social support negatively, and as a further source of stress. Stetz, Stetz, and Bliese (2006) found a buffering effect of social support only for high self-efficacy individuals, but a reverse buffering effect for those with low self-efficacy (i.e., social support exacerbated the negative effects of job stressors on strain).

7.7 Selection implications for personality at work

Psychological testing is basically of two types: aptitude (either intelligence, or types of ability—e.g., spatial, speed, accuracy, programming) and personality (e.g., using Big Five measures). Dorcus and Jones (1950) noted that psychological testing grew rapidly between 1910 and 1948 in the United States, while in the United Kingdom and the rest of Europe it remained at a relatively low level. During the 1980s, personality testing increased in UK organizations' selection procedures (Robertson & Smith, 1989), leading to continued growth in the 1990s (Robertson & Smith, 2001). To some extent this reflected a greater confidence in personality as a predictor of job performance due to meta-analytic studies providing evidence of at least a moderate level of criterion-related validity for personality (Frei & McDaniel, 1997; Hermelin & Robertson, 2001; Ones et al., 1993; Salgado, 1998). In a meta-analytic review of the predictive validity of personnel selection methods in relation to job performance, Hermelin and Robertson (2001) found that personality tests measuring the Big Five fell into the lowest category of validity (where the mean corrected validity ranged from 0 to .25). Among these, they reported that conscientiousness showed the highest mean validity, followed by neuroticism, extraversion, agreeableness, and openness.

Attempts have been made to develop personality tests that have a more specific occupational orientation. A prime example is the Occupational Personality Questionnaire (OPQ) (Saville & Holdsworth, 1984, 1985). The OPQ was developed to measure personality factors deemed to be particularly relevant to occupational environments. The OPQ has three main domains: relationships with people, thinking style, and feelings and emotions, as well as traits and descriptions within each domain. Factor analyzing the OPQ, Matthews, Stanton, Graham, and Brimelow (1990), and Stanton, Matthews, Graham, and Brimelow (1991) found a factor structure that corresponded with the Big Five. Robertson and Kinder (1993) found that OPQ personality variables were significantly associated with job competencies, such as creativity, analysis, and judgment. However, debate continued about the appropriate level of analysis for personality measurement. Ones and Viswesveran (1996) argued that broad measures using the Big Five provided the most appropriate level of analysis, particularly when predicting overall job performance. However, other research has demonstrated that where prediction concerns specific occupational areas, a narrower approach provides better validity (Robertson et al., 2000). Clarke and Robertson (2005) found relatively small validities for the Big Five personality dimensions in relation to injury involvement, but concluded that exploring the predictive validity of lower level facets would yield more convincing levels of validity. For example, there is evidence that sensation seeking is more strongly related to safety behaviors, than is the broader extraversion dimension (Beus et al., 2015).

Numerous difficulties are associated with developing personality tests to predict job performance. One problem is that many jobs involve a wide variety of activities (e.g., the job of a safety and risk professional), making it difficult to find a single test that could validly predict for all aspects of such jobs. As Deary and Matthews (1993) pointed out, in many jobs, where a variety of types of processing (e.g., mental and physical activity) are required, stress and motivation (and other factors) vary over time so that personality trait effects are swamped by overall performance measures and external demands.

Hesketh and Robertson (1993) explained the necessity of examining the relative contributions of personality and situation in job performance as a basis for measurement. Thus, personality tests may most appropriately be used to predict relatively homogeneous aspects of job performance or those aspects that are critical, for example, to safety systems. Developments in this area have focused on providing instruments that reflect the personality requirements specific to a job (Hogan & Rybicki, 1998; Raymark, Schmit, & Guion, 1997; Westoby & Smith, 2000). A more accurate specification of the personality requirements of a job means that these become the focus of the instrument, with less relevant dimensions eliminated, thereby improvding the average validity of the remaining dimensions (Hermelin & Robertson, 2001; Robertson & Smith, 2001). For example, subject-matter experts were involved in the development of a 60-item questionnaire that identified those 16PF scales that were likely to be predictive of specific job performance (Westoby & Smith, 2000).

Although there has been criticism of the validity of personality tests in job selection (Blinkhorn & Johnson, 1990), support for personality testing has generally been strong (Day & Silverman, 1989; Gellatly, Paunonen, Meyer, Jackson, & Goffin, 1991; Tett et al., 1991). Jackson and Rothstein (1993) concluded that personality testing can be a useful component of personnel selection if the following criteria were adhered to

- Use well-constructed and validated personality measure(s)
- Choice of personality measure(s) guided by job analysis and prediction
- Use appropriate statistical analyses to validate the measure(s)
- Evaluated economic benefits with respect to improving job performance

Personality tests should be used in conjunction with one or more other selection techniques, for example, those listed in Summary Text 7.4. Research has shown that combining multiple predictors with low intercorrelations can improve overall validity in predicting job performance (Ones et al., 1993; Schmidt & Hunter, 1998). Another means of combining selection methods is to explore interactive relationships between different predictors, such as cognitive ability and personality. For example, Wallace and Vodanovich (2003b) demonstrated a significant interaction between conscientiousness and cognitive ability in relation to safety performance. In addition to Big Five measures of personality, integrity tests might be useful as part of selection procedures as these are predictive of CWBs (counterproductive work behaviors); however, it has also been noted that CWBs cannot subsume all aspects of workplace safety (Casillas, Robbins, McKinniss, Postlethwaite, & Oh, 2009).

When considering personnel selection in a strategic context, such as one provided by human resource management, the contribution of personnel selection to the organization's corporate objectives needs to be considered as an investment in human resources. Cook (2004) argued for a systematic approach to selection as a means of improving productivity, and it is increasingly recognized that poor selection decisions can be very costly for an organization. One principle of human resource planning is to use selection procedures systematically. Part of this process is to use job analysis, often by observing those doing

---

SUMMARY TEXT 7.4 Selection Techniques Complementing Personality Tests

- *Interviews*—Should be structured and interviewers properly trained
- *Biographical data* (biodata)—Indicate relevant aspects of experience, qualifications, and background
- *Ability tests*—Assess relevant cognitive or behavioral components of job performance
- *Work sample/simulation tests*—Replicate the type of work environment to be encountered for assessing a sample of performance
- *Assessment centers*—Collect data from a range of different tests and exercises that focus upon job (particularly managerial) performance

---

the job and by interviewing present incumbents. The job description drawn up should show these features:

- Responsibilities involved in the job
- Skills and knowledge required
- Authority level and position in organization
- How the job is to be performed
- Personal factors required—for example, age range, qualifications, experience, abilities, and personality factors (required, desirable, undesired)

From a detailed job analysis, including safety and risk aspects of the job, an appropriate personality measure may be a useful component of the selection process.

From work linking personality traits, work behaviors, and safety outcomes (e.g., Hogan & Foster, 2013), it is possible to identify those employees with specific personality profiles linked to job-specific safety behaviors. This would provide information that could be used to tailor training programs.

7.8 Conclusions

From evidence reviewed in this chapter, personality models that have been developed to date have yet to realize their full potential in helping to manage individual risk in the workplace. A major problem with an approach through accident proneness is that injuries are caused by many factors and trying to isolate one, which itself is a collection of different components, is unlikely to be successful. However, as it is always useful to know where to look for solutions to health, safety, and risk problems, it would be a mistake to ignore personality factors merely because of problems with measurement and ambiguous associations with behavior. This is because (1) personality factors have been shown in many studies to be related to aspects of job performance that are relevant to safety and risk, and (2) because personality testing is used extensively in the selection process, which is a critical component of managing human resources strategically.

The personality profile of workers and managers is just one component of a complexity of factors that together are important in managing risk and safety features of jobs and tasks. However, progress on specific ways in which personality factors influence occupational health, safety, and risk has not been spectacular. Nevertheless, there have been a number of advances, particularly in the use of personality testing in personnel selection. Even in this area, further research is needed to inform these developments in relation to safety performance, specifically research on interactions between personality and other selection criteria, such as cognitive ability.

While personality is conceived of, and usually defined as, a relatively enduring set of individual characteristics, personality has been found to change over the lifespan (Lüdtke, Roberts, Trautwein, & Nagy, 2011; McAdams & Olson, 2010; Srivastava, John, Gosling, & Potter, 2003; Tang et al., 2009; Terracciano, McCrae, & Costa, 2010). However, even those personality theorists who consider that a large percentage of the variance in personality is inherited (e.g., Eysenck) believe that behavior that is attributable to personality can be modified and shaped by external influences, a view that is shared, albeit for different reasons, by personality theorists of all persuasions. Therefore, when seeking to modify behavior in the context of managing safety and risk, it would not be correct to think of an individual's personality as immutable.

By using various personality measures (e.g., variants of the Big Five) we can acquire information that can be used to counsel individuals, giving feedback on their strengths and weaknesses in order to encourage change from within. Thus, where personality is likely to be important in the performance of a task or job, then it may be part of the role of the safety and risk scientist practitioner to acquire expertise to assess the personalities of relevant personnel and to act accordingly. In only a small number of cases is it likely to be worth trying to use personality tests to select candidates for jobs involving specific safety or risk components. For example, in some jobs where decision making on risk could have critical consequences, particularly in some senior managerial jobs, it may be prudent to screen candidates so as to exclude those with certain combinations of personality traits. However, a more proactive use of personality tests would be as a basis for assessing training needs for particular types of job, especially where the job incorporates safety critical functions.

In general, the type of job (e.g., managerial, supervisory, operational), together with its safety requirements and responsibilities, should be looked at systematically, for example, using job analysis designed to identify the range of personality requirements of a job. If personality tests are to be used as a selection device, then systematic job appraisal can be used to develop appropriate tests, particularly for safety critical jobs.

chapter eight

Group climate

Organizations increasingly employ teams to achieve organizational goals (Ilgen, 1999) and recognize the benefits of teamworking, where teams are capable of producing higher levels of performance than are individuals (Hackman, 1998). Guzzo (1996) defined teams as social entities embedded in organizations. Teams may come together to undertake a specific range of tasks or a single task that contributes to achieving the organization's goals. There is evidence to suggest that the introduction of teamworking into an organization results in improved organizational performance in terms of financial (Macy & Izumi, 1993), efficiency, and quality measures (Applebaum & Batt, 1994). A review of survey-based research using quantitative measures demonstrated that teamworking is associated with improved organizational performance, across behavioral, operational, and financial measures (Delarue, Van Hootegem, Procter, & Burridge, 2008). A study conducted by Birdi et al. (2008) tracked human resources management (HRM) practices and financial performance for more than 22 years, and found evidence of productivity gains, although these tended to appear 6 to 9 years after implementing teamworking. However, teams do not always make optimum decisions (or even the same quality of decisions made by the most capable team members) because of psychological issues (e.g., Allen & Hecht, 2004), including process loss (Steiner, 1972). Process loss can arise due to a number of intra-group problems, such as introversion, social conforming, diffusion of responsibility, and groupthink, among others.

Groups operate in many occupational contexts, from the formal setting of a board meeting to the focused discussion of a task force, or from the monitoring function of a safety committee to the ad hoc spontaneity of a demonstration against a shared grievance. Being with others, even in an ad hoc or loosely formed group, influences our behavior. For example, when faced with an emergency we are more likely to respond quickly if we are on our own than if we are in the presence of others; a phenomenon known as *diffusion of responsibility* (Latané & Darley, 1968). If others do not react decisively, then it is likely that we will perceive the situation as not being serious, particularly if circumstances are ambiguous. This slowness to respond may occur in an emergency when life or property is at risk. For example, if an individual alone in a room sees smoke coming from under the door, he or she is likely to respond quickly. However, a group confronted with the same situation reduces the likelihood of rapid response because of an inclination to discuss the nature of the threat and how best to deal with it (Latané & Darley, 1968). This may be a typical response during a fire on premises where fire drills are under-rehearsed and employees' attitudes reflect the sentiment that "fire drills are a needless imposition." When frightened or threatened, people seek others' company, preferably those frightened by the same event so as to compare their feelings with others to see if their fears are justified. Group support in reducing anxiety while waiting for a potentially painful experience (e.g., a diagnostic medical intervention or an injection) is critical, even in situations where group members do not communicate directly with each other (Wrightsman, 1960). Group membership can be a significant source of social support, which can act as a buffer against negative effects of stress and as a positive influence on safety-related behavior (Nahrgang, Morgeson, &

Hofmann, 2011). From an evolutionary perspective, groups were the predominant form of human society during the major part of our existence. It is not therefore surprising to find powerful social interactions and emotions arising within a group context. Groups predate larger organizational forms by many millennia, which could account for the relative ease with which we are able to identify with kinship, community, and workgroups compared with large organizations, and perhaps also partly why such organizations require complex legal and financial support structures to enable them to survive; unlike informal groups, which could be considered to be the most "natural" human social unit.

In its contemporary guise, group activity (where a group may range in size from two, a *dyad*, to a much larger number) is central to organizational functioning. Increasingly, it is recognized that the effectiveness with which groups or teams perform is critical to an organization's survival and success. Thus, it is important that anyone with an interest in extending motivation and reward beyond the individual level has some appreciation of the role and function of groups within an organization. In terms of workplace safety, one of the most powerful influences on employees' safety-related behavior is the *safety climate*; that is, shared perceptions of the importance of safety relative to other organizational goals (Zohar, 1980). Although individual perceptions of the priority given to safety at an organizational level will influence an individual's behavior (Clarke, 2006), this effect is stronger at the group level (Beus, Payne, Bergman, & Arthur, 2010; Clarke, 2006). This chapter considers how teams operate, some aspects that can go wrong and some techniques for overcoming difficulties, specifically in relation to safe performance. There is a particular focus on group-level safety climate and its effects on safety-related behavior.

8.1 Teams and safety performance

The safe performance of teams with a high level of interdependence will depend critically on group-level processes; for example, flight crews or surgical teams. Tesluk and Quigley (2003) suggested that group processes within teams influence safety outcomes, including

- Monitoring team members' performance and providing feedback to others who are not working according to proper procedures
- Communicating and exchanging information
- Helping team members when needed
- Assisting with production-related tasks by ensuring that team members have what they need to know in order to complete their tasks effectively
- Provision of necessary assistance to complete work in a timely manner

Although teams may not always be necessary, there are a number of safety-critical operations that can only be managed by individuals working within teams, such as in health care (e.g., surgery) and aviation (e.g., commercial flights), where effective group processes are essential for team performance. For example, lack of communication between flight crew and the cabin crew was a contributory factor in the Kegworth air disaster (see Summary Text 8.1), in conjunction with a number of other mistakes.

This problem is not exclusive to the flight deck as similar incidents have been recorded in a medical context, where the hierarchy that exists between nursing staff and physicians has acted as a barrier to communication. For example, Helmreich (2000) described the

SUMMARY TEXT 8.1 Summary of the Airline Crash at Kegworth

On January 8, 1989, at 20:25, a British Midland Boeing 737-400 series crashed into a bank alongside the M1 motorway at Kegworth, England, just short of the East Midlands Airport runway. Forty-seven passengers died from their injuries and most of the remainder who were onboard suffered serious injury. The active failure was that the flight crew shut down the No. 2 engine after a fan blade had fractured in the No. 1 engine. This engine subsequently suffered a major thrust loss due to secondary fan damage after power had been increased during the final approach to land. Factors that affected the incorrect response of the flight crew included those outlined as follows:

- Symptoms of engine failure—heavy vibration, noise, and smell of smoke were outside their training and expertise.
- Previous experience of vibration gauges on other planes, which, unlike the 737-400 gauges, tended to be unreliable.
- Secondary position of the vibration gauges and absence of any warning light or labeled danger zone.
- Lack of familiarity with the automatic fuel system, which meant that when the healthy No. 2 engine was throttled back, the automatic fuel system was shut off thereby resulting in a normal flow to the damaged No. 1 engine persuading them that they had (by trial and error) correctly identified the defective engine.
- No cabin crew or passengers who could see the flames emanating from the No. 1 engine informed the flight crew which engine was involved. The flight crew had no means of seeing which engine was faulty and their instruments gave no strong clue that the No. 1 engine was faulty, even when No. 2 engine had been shut down.

When the flight crew were about to review the action they had taken, they were interrupted by messages from flight control and did not return to the review process. Although the flight crew was primarily blamed for the crash, there were other contributory factors, which were:

- Design, manufacture, and inadequate testing of the newly designed engine
- Inadequate training on the new aircraft
- Inadequate procedures for determining which engine to shut down
- Position and display features of critical instruments
- Lack of communication between the cabin crew and the flight attendants

Source: Great Britain: Department of Transport, Air Accidents Investigation Branch (1990). Aircraft Accident Report 4/90: Report on the Accident to Boeing 737-400 G-OBME near Kegworth, Leicestershire on 8 January 1989. London, UK: HMSO.

SUMMARY TEXT 8.2 Example of a Fatal Medical Incident

An 8-year-old boy was admitted for elective eardrum surgery. He was anesthetized and an endotracheal tube inserted, along with an internal stethoscope and temperature probe. The anesthetist did not listen to the chest after inserting the tube. The temperature probe connector was not compatible with the monitor (the hospital had changed brands the previous day). The anesthetist asked for another but did not connect it; he also did not connect the stethoscope.

- Surgery began at 08:20 and carbon dioxide concentrations began to rise after about 30 minutes. The anesthetist stopped entering CO_2 and pulse on the patient's chart. Nurses observed the anesthetist nodding in his chair, head bobbing; they did not speak to him because they were afraid of a confrontation.
- At 10:15, the surgeon heard a gurgling sound and realized that the airway tube was disconnected. The problem was called out to the anesthetist, who reconnected the tube. The anesthetist did not check breathing sounds with the stethoscope.
- At 10:30, the patient was breathing so rapidly that the surgeon could not operate; he notified the anesthetist that the rate was 60/min. The anesthetist did nothing after being alerted.
- At 10:45, the monitor showed irregular heartbeats. Just before 11:00, the anesthetist noted extreme heartbeat irregularity and asked the surgeon to stop operating. The patient was given a dose of lignocaine, but his condition worsened.
- At 11:02, the patient's heart stopped beating. The anesthetist called for code, summoning the emergency team. The endotracheal tube was removed and found to be 50% obstructed by a mucous plug. A new tube was inserted and the patient was ventilated. The emergency team anesthetist noticed that the airway heater had caused the breathing circuit's plastic tubing to melt and turned the heater off. The patient's temperature was 108°F. The patient died despite the efforts of the code team.

Source: Helmreich, R.L., *Br. Med. J.*, 320, 781, 2000.

catalogue of medical errors that led to a young child, undergoing routine surgery, dying in the operating theater (see Summary Text 8.2).

Work by Edmondson (2003) highlighted the negative effects that status hierarchy has on collaborative learning, as those with different hierarchical status find it difficult to communicate effectively across professional boundaries (e.g., nurses vs. physicians). Nembhard and Edmondson (2006) examined the influence of leader inclusiveness (defined as the extent to which a leader demonstrates an openness and appreciation for others' contributions) in relation to the effects of hierarchical status on perceptions of psychological safety (i.e., that the team is safe for interpersonal risk-taking, such as speaking up). Leader inclusiveness was found to play a moderating role, such that high leader inclusiveness weakened the impact of status on psychological safety. Leaders who make their employees feel comfortable speaking up and sharing information are less likely to encounter problems with people being inhibited by status differences. Casey and Krauss (2013) found that effective safety communication and coworker support for safety within teams was strongly associated with employees' safety-related behaviors in a sample of South African mineworkers.

Coworker support may lead to assistance with tasks (Chiaburu & Harrison, 2008), such as coworkers intervening to help colleagues to detect and recover errors (Edmondson, 1996), which in turn reduces the likelihood of accidents and injury. Furthermore, coworker support has been found to move employees toward active involvement in safety, such as engaging in safety programs (Goldberg, Dar-El, & Rubin, 1991) and speaking up about safety (Tucker, Chmiel, Turner, Hershcovis, & Stride, 2008). Therefore, the likelihood of accidents will be affected both through coworkers' direct support for safety compliance, and through the encouragement of safety participation. Coworker support has a direct effect on the reduction of role stressors, through the effect of frequent, high-quality exchanges with coworkers, and the provision of information that can reduce role conflict, role ambiguity, and role overload (Chiaburu & Harrison, 2008). The authors also found evidence of a partial mediation effect via role perceptions on task performance. This would suggest direct effects on behavior, but also a mediated effect through the experience of work stressors. A number of studies have demonstrated that increased coworker support leads to fewer occupational injuries (Iverson & Erwin, 1997; Sherry, 1991). Another mechanism through which coworkers may influence employees' safety behaviors would be via behavioral modeling. A study by Jiang, Yu, Li, and Li (2010) found that if employees held positive views of their coworkers' level of safety knowledge and behavior, it led to improvements in their own safety performance. This would suggest that coworkers act as behavioral role models, and that the observation of safe practices performed by others encourages positive change in employees' own behavior.

8.1.1 Cohesion

Group cohesion, which is advanced by group members sharing common values, beliefs, and objectives, promotes the sharing of similar ideas and their mutual acceptance. It might be viewed as the tendency for a group to stick together and remain united in pursuit of its task-related goals. Members of a cohesive group agree among themselves how best to achieve group objectives, emphasize the need for close cooperation in order to complete various tasks effectively, and create conditions for satisfying members' personal needs. The more benefit that members derive from group membership, the more cohesive the group is likely to be. Group cohesion is positively related to performance, particularly where tasks are highly interdependent (Casey-Campbell & Martens, 2009; Gully, Devine, & Whitney, 1995); longitudinal data supports the directionality of this relationship over time, such that high cohesion leads to enhanced performance (Tekleab, Quigley, & Tesluk, 2009).

In a study of nurses' occupational injuries, Hemingway and Smith (1999) found that peer cohesion significantly predicted reported injuries and near injuries; such that high levels of cohesion tended to result in fewer safety incidents and accidents, and also a greater openness in terms of reporting accidents. Cohesive groups tend to develop high levels of psychological safety, which allows group members to suggest alternative ways of working, admit to mistakes and problems, and engage in collaborative learning (Edmondson, 1999). Workgroup cohesion has emerged as an important variable in predicting both safety initiative and safety compliance (Simard & Marchand, 1995, 1997). Multilevel research has shown that workgroup cohesion is linked with organizational citizenship behaviors (OCBs) (Chen, Tang, & Wang,

SUMMARY TEXT 8.3 Illustration of Negative Impact of Group Loyalty upon Safety

The function of a factory unit was to modify rod-shaped machine tools by cutting or bending them. Before modifying them, one end of each pen-sized tool was dipped in a protective molten plastic substance. After modification some of the tools were sandblasted to make them look better. Almost every one of these actions was undertaken in a grossly unsafe manner. One Monday, the manager told six of his subordinates to make the place presentable because the factory inspector was coming around. Three of them were asked to tidy up around the machines and the other three to pick up the boxes of tools from the gangway and place them on a long bench. The manager told the group that they could replace the boxes as soon as the visit was over, and gave them a wink, because the bench was required for other things.

The factory inspector seemed to be viewed as an enemy. The men grumbled about the visit but the manager said, "Surely we don't want people, like factory inspectors, finding fault with our unit, lads!" This prompted jokes about setting booby traps for the factory inspector. When the factory inspector left, there was evidence of a lot of antisafety behavior. In this case, the behavior would suggest that there appeared to be mindless devotion to the group, particularly in the face of an outside authority figure with powers of sanction. The "them and us" sentiment was aroused by the factory inspector's visit, but the them in this case was the factory inspectorate.

This account was reported as a personal communication to the first author by a trusted source.

2009; Kidwell, Mossholder, & Bennett, 1997). In relation to workplace safety, group cohesion has been associated with active caring, where employees actively monitor and intervene in their coworkers' safety behavior in order to safeguard their well-being (Burt, Gladstone, & Grieve, 1998; Burt, Sepie, & McFadden, 2008; Roberts & Geller, 1995).

Although group cohesion usually has positive associations, under some circumstances it can have an adverse effect on safety as illustrated in Summary Text 8.3.

Strong pressures toward conformity can reduce team adaptability and the ability to learn, and can lead to inappropriate decision making. A meta-analysis of studies linking cohesion with decision making showed that cohesion was not directly associated with the quality of decision making, but did lead to lower quality decisions under some circumstances, especially when group cohesion was based more on interpersonal attraction than task commitment or group pride (Mullen, Anthony, Salas, & Driskell, 1994). A highly cohesive group may suffer symptoms of *groupthink*, a term introduced by Janis (1972) to describe decision making within a small group in the U.S. government during the Bay of Pigs crisis in the 1960s.

8.1.2 Group discussion and decision making

Decisions taken by a group are liable to have a greater effect on an individual's behavior than if a decision is already made by, for example, a speaker who instructs an audience about the course of action to follow (Lewin, 1958). Lectures tend to result in passive listening, individual members of the audience using their experiences as a basis for accepting or rejecting ideas suggested. Also, each individual is unaware of what other members of the audience are going to decide, and none is therefore exposed to a new social norm as a guide. However, in discussion, group members exchange views and consider advantages and disadvantages of various courses of action. Decisions emerging from such discussion become norms and if decisions are to be manifested in behavior it is likely that most or all group members will act in accordance with group decisions. For example, a study involving three companies in the explosives industry in Sweden found that group decision making resulted in positive efforts to reduce health and safety risks, and that discussion group participants benefited from greater awareness and understanding of problems connected with health and safety at work, and accepted remedies suggested (Kjellén & Baneryd, 1983). While there are benefits to group decision making, there are circumstances where groups are likely to make less effective decisions than individuals (Allen & Hecht, 2004). Group decision making may be less effective, for example, when

- Tasks or problems are simple or routine
- Problems have a correct solution
- It is difficult to demonstrate solutions to group members
- Problems require subtle, logical reasoning

Over time, team members will develop a mutual understanding of each other and the task environment, leading to a *shared mental model*. At an individual level, a person will tend to arrange knowledge into an organized pattern to represent a working model; within teams, this mental model can be shared across team members to the extent that individual mental models are consistent (Kozlowski & Klein, 2000). Mathieu, Heffner, Goodwin, Salas, and Cannon–Bowers (2000) demonstrated that shared mental models can significantly influence such group processes as communication and, ultimately, performance. Team mental models, comprising taskwork (i.e., team procedures, tasks, and equipment) and teamwork (i.e., team interaction processes) have been linked to team performance of action teams in the field (Lim & Klein, 2006). Shared mental models may contribute to effective team performance through the ability of team members to adapt to each other's needs and to unanticipated environmental demands. For example, Foushee, Lauber, Baetge, and Acomb (1986) showed that experienced flight crews were better able to coordinate their actions as a team and to monitor and recover each other's errors. Further work has demonstrated that task-shared mental models improve team performance due to the mediating effect of *collective efficacy* (i.e., shared belief in the group's ability to succeed), whereas team-shared mental model tends to act as a moderator, rather than having a direct effect on performance (Mathieu, Rapp, Maynard, & Mangos, 2009). Tesluk and Quigley (2003) suggested that collective efficacy, which they defined as the group's belief in its ability to work safely, will influence team safety performance, particularly in meeting the challenge of increasing production demands. Experimental studies have shown that team performance can be improved through *cross-training*, where team members develop enhanced mutual understanding by gaining experience of each other's roles (Blickensderfer, Cannon–Bowers, & Salas, 1998; Cannon–Bowers, Salas, Blickensderfer, & Bowers, 1998; Marks, Sabella, Burke, & Zaccaro, 2002).

There is evidence that in teams that work together for long periods, familiarity can lead to overconfidence, complacency, and increased errors (Leedom & Simon, 1995). Shared mental models developed over time can lead to *discussion bias*, where team members tend to discuss common information rather than unique information, which leads to suboptimal performance in situations where uniquely held information is important. Kim (1997) found that groups with both task and team experience demonstrated the largest discussion bias. The author argued that this effect was due to the "curse of knowledge," where individuals tend to assume that information they hold uniquely is shared. Individuals are more susceptible to this effect when situations are very familiar.

Another issue with the functioning of groups relates to *groupthink*, which can occur whenever groups are involved in decision making, particularly when a group is isolated from alternative views or external advice. Any of the processes described in Summary Text 8.4 may occur as a result of groupthink.

SUMMARY TEXT 8.4 Characteristics of Groupthink

- Excessive optimism leads to a tendency to take risks because of the shared illusion of invulnerability.
- Warning signals, which, if acknowledged, could lead to a reconsideration of policy as discounted or ignored.
- Unquestioned belief in the morality or self-righteousness of the group, which provides scope for ignoring ethical consequences of decisions.
- Tendency to underestimate the significance or strength of enemy or competitor groups—perhaps manifested in descriptions of leaders of these groups as weak or stupid.
- Reluctance to deviate from what appears to be group consensus. The deviant may be listened to at first and then questioned before appeals to logic and group loyalty are made. The deviant is then counseled and may capitulate at that stage. A persistent deviant is likely to be ignored and then ostracized. Cohesion is usually retained if there is only one deviant. If there is more than one, then the group might fragment as two or more can use their strength to influence others (in Asch's conformity experiment, the presence of one other supporter for the true participant virtually guaranteed that the participant would stick with their view). A lone deviant will eventually fail to convince other group members of their case. Thus, any potential deviant remains silent about his/her misgivings or doubts and is capable of convincing themselves of a lack of substance in these doubts. In any case, there would be direct pressure on any member who expressed strong arguments against the group's position as being contrary to expectations of loyal membership. Thus, individuals self-censor contrary views.
- Belief that judgments of members are unanimous, simply because members have subscribed to the majority view, creates an illusion of unanimity. Silence is taken as assent, along with self-censorship. Being insulated from outside views assists in developing unanimity.
- New information is likely to be rejected on the grounds that it might compromise or conflict with decisions already taken (We've made up our mind; don't confuse us with the facts!).
- Some members take it upon themselves to protect the leader and fellow members from adverse information about the morality and effectiveness of past decisions. Expert opinion that challenges the wisdom of the group's decisions may be subtly undermined.

Source: After Janis, I.L., *Victims of Group Think: A Psychological Study of Foreign Policy Decisions and Fiascos*, Houghton & Mifflin, Boston, MA, 1972.

Consequences of groupthink include poor decision making and inadequate solutions to problems. A limited number of alternatives are considered, potential gains from alternatives may be overlooked, and assessments of the cost of alternatives that are rejected by the group are likely to be ignored. The group fails to obtain expert opinion on losses or gains; instead there is a tendency to use selective bias in evaluating expert opinion. Group members tend to display a positive interest in facts and opinions that support their preferred policy, but are hostile to information that challenges their views. There is a tendency not to have contingency plans to cope with setbacks. In an analysis of events leading up to the Chernobyl disaster, Reason (1987) focused on two perspectives: the first dealt with cognitive difficulties that people have in coping with complex systems; the second was concerned with the "pathologies" of small cohesive groups, as in groupthink. Reason (1987) identified five groupthink symptoms as being attributable to the Chernobyl operators, which are shown in Summary Text 8.5.

The *Challenger* shuttle disaster (1986) is another example of the contribution of groupthink within a small group leading to a major disaster (see Moorhead, Ference, & Neck, 1991, for a discussion). Criticisms of groupthink theory include methodological weakness (Tetlock, 1979) and theoretical incompleteness (e.g., Longley & Pruitt, 1980; Steiner, 1982). Furthermore, empirical evidence to support the model is mixed (Jones & Roelofsma, 2000). Certain evidence undermines some of the fundamental tenets of groupthink; for example, whereas highly cohesive groups with strong, directive leaders are hypothesized as most vulnerable to groupthink, a number of studies have failed to support this link (e.g., Park, 1990; Wittebaum & Stasser, 1996). Defective decision making can occur in newly formed groups, where cohesion is low as such groups lack the security in their roles and status to challenge one another (Leana, 1985). On the other hand, more cohesive groups should develop norms that allow more open discussion. Developing norms that promote an open and constructive environment for group discussion was associated with high-performing teams, whose members were not afraid to express ideas and opinions (Jehn, 1995). Manz and Neck (1995) suggested a rational approach to decision making that could help to avoid groupthink, including the criteria listed below:

- Encouraging divergent views
- Open expression of concern/ideas
- Awareness of limitations/threats
- Recognizing members' uniqueness
- Recognizing views outside the group
- Discussing collective doubts
- Using nonstereotypical views
- Recognizing ethical and moral implications

8.1.3 Shared leadership and self-managing teams

Team leaders play an important role in team performance (e.g., Eden, 1990; Zaccaro & Marks, 1999); with leadership style having a significant influence on group processes, such as consensus decision making, which in turn influences team effectiveness (Flood et al., 2000). Research has also focused on *shared leadership*, which is an emergent property of a team and has been defined as a group process in which leadership is shared among, and stems from, team members (Pearce & Sims, 2002). Shared leadership within a team tends to encourage discussion and rapport-building within the team and leads to lower

SUMMARY TEXT 8.5 Chernobyl Disaster: An Illustration

The world's worst nuclear power disaster occurred at Chernobyl (in the Ukraine) on April 25–26, 1986. Tests were being carried out on No. 4 reactor, which involved shutting down the reactor and switching off the emergency core cooling system. A series of operational errors and procedural violations led to an out-of-control chain reaction, resulting in explosions that destroyed the reactor core.

The operators, probably all Ukrainians, were members of a high-prestige occupational group, and had recently won an award. They probably approached the task with a "can do" attitude with some confidence in their ability to "fly" the reactor. Like other nuclear power plant operators, they would operate the plant using process feel, rather than a knowledge of reactor physics. Their immediate aim was to complete the test as quickly as possible, get rid of the experimenters, and to shut down the plant in time for the start of the Tuesday maintenance program. But they had forgotten to be afraid of the dangerous beast they were driving. The Russian report expressed it thus:

> They had lost any feeling for the hazards involved. The experimenters, akin to a development group, were electrical engineers from Moscow. Their aim was quite clear: to crack a stubborn technical problem once and for all. Although they would have set the goals for the operators before and during the experiment, they would not, themselves, have known much about the actual operation of a nuclear power station.

The Russian report makes it evident that the engineer in charge of this group knew little or nothing about nuclear reactors. Together the two groups made a dangerous mixture. The experimenters were a group of single-minded but non-nuclear engineers directing a group of dedicated but overconfident operators. Each group probably assumed that the others knew what it was doing. And both parties had little or no understanding of the dangers they were courting or of the system they were abusing.

The operators' actions were consistent with an illusion of invulnerability. It is likely that they rationalized away any worries (or warnings) that they might have had about the hazards of their endeavor. Their single-minded pursuit of repeated testing implied an unswerving belief in the rightness of their actions. They clearly underestimated the opposition: in this case, the system's intolerance to being operated within the forbidden reduced-power zone. Any adverse outcomes were either seen as unlikely or possibly not even considered at all. Finally, if any one operator experienced doubts, they were probably self-censored before they were voiced. The above speculations suggest that the group aspects of the situation were prominent.

Source: After Reason, J.T., *Bull. Br. Psychol. Soc.*, 40, 201, 1987.

levels of team conflict (Gupta, Huang, & Niranjan, 2010). Shared leadership is associated with team performance (D'Innocenzo, Mathieu, & Kukenberger, 2014); for example, shared leadership was found to predict client-rated performance in a study of 59 consulting teams (Carson, Tesluk, & Marrone, 2007).

Earlier work has focused on autonomous, or self-managed, workgroups, where there is no formally assigned leader, but where the leadership role is distributed across team members. Empirical studies have supported positive effects on productivity and other performance measures, although there is less certainty regarding effects on well-being, motivation, and absenteeism (Fisher, 2000; Goodman, Devadas, & Hughson, 1988). Leach, Wall, Rogelberg, and Jackson (2005) found that team autonomy was associated with performance and strain through teamwork knowledge, skills, and abilities. A review of 23 studies of autonomous workgroups identified two distinct views relating to the benefits of such teams (Metlay & Kaplan, 1992); one noting positive benefits associated with reduced rates of turnover and injuries, the other identifying difficulties related to increased stress levels. The stress literature suggests that increased control would mitigate stress outcomes, such as depression, and improve motivation; however, the way in which decision latitude is devolved in autonomous workgroups may affect feelings of empowerment within a team. For example, minor decisions, such as distribution of work may be delegated to the work team, while the most important decisions (from an organizational perspective), such as productivity targets, are retained centrally. Thus, team members may find that they have increased responsibilities, without experiencing increased personal control (Manz & Angel, 1996).

Research from the 1960s and 1970s highlighted some safety benefits of reorganizing workers into autonomous work teams (e.g., Goodman, 1979; Trist, Higgin, Murray, & Pollock, 1963; Trist, Susman, & Brown, 1977; Walton, 1972). In the case study of a UK coal mine, Trist et al. (1963) found that miners who were organized into teams that rotated tasks and functions, as opposed to conventional teams, experienced no change in lost-time injuries, while these rose significantly for conventional teams. Benefits of this way of working may relate to the increased knowledge of their own and other miners' tasks, facilitating better coordination between team members and reduced errors, together with effects of increased variety, which reduces boredom and fatigue. Goodman (1979) evaluated autonomous work teams in a longitudinal study of a coal mine, finding that observed safety behaviors demonstrated a significant improvement. However, other indicators, such as violations and incident data, were ambiguous. Later research (Hechanova-Alampay & Beehr, 2002; Pearson, 1992; Roy, 2003) supported the argument that autonomous work teams have a positive effect on safety, although Cohen and Ledford (1994) found no significant effect for teams in the service sector. Roy (2003) examined the operation of autonomous workgroups in 12 companies in Canada to evaluate the companies' perspectives in relation to health and safety. The study noted that in several cases the roles played by the formal safety committee had devolved to the work teams themselves, so that responsibility for identifying failings and introducing corrective and preventive safety measures now rested with those who actually carried out the work. Pearson (1992) also noted this characteristic of autonomous work teams. The increase in safety responsibilities may form the motivation of work teams to take greater ownership of safety issues. However, Roy observed that there are dangers associated with delegating health and safety responsibilities, because managers may be perceived as losing commitment to safety if they assume that work-based teams are undertaking this responsibility. It is vital that managers continue to take a leadership role in safety, as self-managed teams are more aware of the discrepancy between management rhetoric and reality on the ground. Developing appropriate group norms is also an issue, particularly where teams are set production targets associated with team bonus payments. In this case, team members may be subject to even more intense pressure from coworkers to reach production targets than in traditional settings where such pressures are exerted by supervisors. Another leadership role, of monitoring and managing behavior, when devolved to the team, will involve team members monitoring each other's work; this needs to be accepted within the team, otherwise it could become a source of resentment and conflict. Among others, Pearson and Goodman have noted the difficulty of isolating effects of autonomous work teams on safety. It is possible that autonomous teamworking is not responsible *per se* for improving safety, but that employing autonomous teams is one hallmark of a high-performing company (Roy, 2003). As high-performing companies are most likely to have a range of sound health and safety management systems in place, these systems will also contribute to high safety performance and low injury rates.

More recently, studies have demonstrated the importance of shared leadership in safety-critical teams, for example, in health care. Kunzle et al. (2010) investigated the importance of shared leadership for the performance of anesthesia teams; they found that high-performing teams were characterized by shared leadership (between residents and nurses), whereas in low-performing teams, there was less emphasis on shared leadership (residents demonstrated significantly higher levels of leadership behavior than nurses did). A meta-analysis conducted by D'Innocenzo et al. (2014) found that the relationship between shared leadership and team performance was moderated by task complexity, such that shared leadership was less effective when task complexity was high. The authors argued that highly complex situations may be best managed by fewer leaders as shared leadership becomes too difficult to manage; they gave the example of a cockpit crew that shared leadership during stable times, but during a crisis, leadership shifted to a single individual to ensure safety and execution of an emergency plan.

8.1.4 Intergroup relations

Membership of one group could predispose members to view other groups with suspicion. An illustration of this can be demonstrated by experiments conducted to reduce friction and prejudice between hostile groups (Sherif, 1967). Members of hostile groups were brought together socially, and accurate and favorable information about one group was communicated to the other. Leaders of the two groups were brought together to bring their influence to bear. However, taking these measures as a way of developing social contacts as a means to reduce conflict did not work; social contacts in these circumstances may only serve to intensify conflict because favorable information about a disliked group may be ignored or reinterpreted to fit negative stereotyped notions about the other group. A workable strategy for achieving harmony between groups in conflict in this case was to bring the groups together to work toward a common goal (e.g., working on a project requiring active cooperation between the groups for successful completion). It is also necessary for successful completion of the task to have important outcomes for the groups. In the 1986 Chernobyl disaster, a nuclear power plant was destroyed as a result of a combination of factors, including human error (Munipov, 1991). In seeking to explain the events leading up to the catastrophe, Reason (1987) referred to two groups at the plant, operators and experimenters, and relationships between them. Key observations from his analysis are shown in Summary Text 8.5.

8.2 Group norms and safety performance

Group membership increases the likelihood of having one's attitude or outlook changed as a result of exposure to group influences. This is particularly so when a reference group is taken as a guiding light by the individual. For example, many students at an exclusive residential college in the United States changed their attitudes as a result of their college membership, treating their contemporaries and senior staff as a positive reference point; however, some students behaved differently and did not succumb to the prevailing progressive attitudes because of their attachment to opposing attitudes derived from experiences outside the college or by remaining independent in outlook (Newcombe, 1943). Applying this finding to safety, it might be expected that a person with "regressive" views on safety who joins a group within an organization that has a high regard for good safety practices, will experience a shift in his or her attitude when the new group is used as a positive reference point. Whether a person changes his or her attitude as a result of membership of a group depends upon the

- Gulf between individual and group attitudes
- Initial strength of the attitude
- Individual personality (for example, how readily a person may be "reconditioned")

An important feature of group influence is social comparison. According to social comparison theory, we tend to compare ourselves with others to test our ideas in a variety of social situations (Festinger, 1954). Sometimes this is to validate our beliefs when another person holds beliefs that are similar to our own; at other times we want to make the correct response in a particular situation; for example, the best way to behave at an interview. We may investigate other people's views before considering the most suitable views to express on religious, social, and political issues as well as use of a particular vocabulary in conversation or the most appropriate clothes to wear at a social gathering. Safety and risk professionals are continually comparing their own views on professional matters with those of other experts in the field, as well as with those of line managers who implement safety policy, for example. As a validity check, people compare their judgments on particular issues with those of others in close proximity.

Group norms and expectations exert powerful effects on individuals' safety-related behavior. For example, in a manufacturing plant where incentive payments are linked to production targets, there may be intense social pressure applied to team members who refuse to waive safety rules in order to reach the targets that would trigger bonus payments. There is a danger that, under these circumstances, group norms that embrace unsafe, rather than safe, behaviors may develop (Roy, 2003). For two classic illustrations of the power of groups to influence individual member views and behaviors see Summary Text 8.6.

8.2.1 Group norms and expectations

Norms are rules or standards established by group members to denote acceptable and unacceptable behaviors. Norms can cover a variety of situations; for example, quantity and quality of output, production methods, how individuals interrelate, and appropriate behavior. As with other activities, our behavior with respect to risk-taking is very much influenced by the company we keep, especially our peer group as well as by wider social norms. Thus, while attitudes may be important in influencing our behavior, the power of a group norm or a wider social norm to determine our behavior should not be underestimated.

SUMMARY TEXT 8.6 Two Classic Studies of Group Norms

Group norms were first described in an early classic U.S. study of groups of production workers at the Hawthorne Western Electric works near Chicago (Roethlisberger & Dickson, 1939) in which informal norms were established to set an acceptable level of output. Sanctions were used to denote disapproval of deviation from these norms and pressure (e.g., name calling, ostracism, or mild physical assault) was applied to deviants to encourage them to conform. The group also applied social pressure on work quality inspectors and supervisors to get them to conform to the group's standards. Although these studies have been criticized (Franke & Kaul, 1978), they were very influential in giving rise to the human relations school of management, which is part of the lineage of the soft side of HRM (human resources management). The three main components were

1. Recognition of the prime function of social interaction among group members
2. Relevance of the informal group at work
3. Importance of taking an interest in workers—generalized as the *Hawthorne Effect*

An early UK study of the effects of group norms on output levels (Lupton, 1963) found a restrictive norm in one factory aimed at regulating output and stabilizing income; this was referred to as the fiddle. In another factory, no such restrictive norm existed. The difference between the two situations was accounted for by economic and social influences, which dictated attitudes to productivity. In this study, group norms related to production levels were significantly influenced by the different orientations that workers brought to their jobs.

Expectations of fellow workers and management, for example, with respect to adherence of safety rules, can strongly influence how individuals behave. Empirical studies have supported the significant influence of group norms on individual work behaviors, including absenteeism (e.g., Bamberger & Biron, 2007; Biron & Bamberger, 2012) and job performance (e.g., Lichtman & Lane, 1983).

Kelman (1958) expressed the extent to which an individual relates to the norms or expectations of a group or organization in terms of three levels. His theory of attitudes can also be related to group behavior.

- At the first level, compliance, an individual complies because of an organizational rule to behave in a certain way (e.g., to wear a safety helmet) and because of sanctions that apply in the case of breaches.
- The second level, identification, means that the worker wears a safety helmet because other group members do and he or she does not want to stand apart from the group.
- At the third level, internalization, the worker wears a helmet because he or she considers it to be the best way to behave in response to the risk.

Kelman's model illustrated that behavior may be influenced by the organization imposing rules (and ensuring workforce compliance) or by groups of workers deciding to behave in a certain way (i.e., a norm) and encouraging identification with this behavior among group members. However, only when individuals themselves believe (i.e., internalize the view) that to behave in a certain way is correct, is their own (safe) behavior likely to be consolidated. Subsequently reinforcing individual behavior or inducing behavioral change through organizational rules and group norms that are consistent with this behavior can then provide powerful support for an individual's behavior. Group norms are often not explicitly defined and it is only when they are breached that they become obvious. A worker who ignores a group safety norm by, for example, by persistently ignoring safety rules, may experience pressure from the other group members to conform using such methods as verbal or physical coercion, silence, black-listing, or expulsion from the group. Where a group norm is strongly held (i.e., approval shared throughout the group) and the group is highly cohesive, the more strongly this pressure is likely to be applied. An example of a social norm acting to the disadvantage of safe work practice is reflected in the experience of a worker in the telecommunications industry, described in Summary Text 8.7. Group norms are analogous with individual attitudes and may be changed through similar types of processes. Often people's own experience is a powerful change agent, as in the example in Summary Text 8.7.

Group norms and expectations can be significant influences on workers' behavior, for example, in relation to deviations from safety rules, or violations. Reason (1993) defined violations as "deliberate infringements of safe working practice." However, this definition hinges upon how one defines "safe" (e.g., do company rules always provide the safest way of working, or do workers sometimes know safer shortcuts?); defining violations in terms of "deviations from a norm" widens the understanding of worker behavior, as deviations can occur inter alia in relation to the factors listed below:

- Rules, standards, or regulations—Formulated by the organization, for example, in response to previous incidents, or from a risk assessment
- What is regarded as normal or usual—Determined by group norms and expectations
- What is adequate or acceptable—Related to injury risk

SUMMARY TEXT 8.7 Example of a Social Norm Being Opposed by a Single Worker, Leading to Norms Changing

The worker insisted on wearing safety gloves during certain tasks, a practice not ingrained in established group norms. Pressure was put on this worker to change his behavior and conform. At first disapproval took the form of remarks, such as sissy and reference to how the gloves did not fit well. In fact, it was possible to return badly fitting gloves and obtain gloves that fitted. The supervisor, a senior technician, who prided himself on his speed and masculinity, felt strongly about the worker wearing safety gloves and eventually instructed him to stop wearing them. A second line supervisor also made derogatory comments about wearing the gloves, maintaining that the practice reduced productivity. However, it took a couple of incidents, in which splinters from a telegraph pole entered the glove rather than the finger, to convince other members of the workgroup of the value of safety gloves. Eventually, the supervisor wore gloves during certain processes and it became a group norm to wear them.

Source: After Rosario del Grayham, D.A., *Safety and Health Practitioner*, January 17–22, 1984.

Deviating from a company safety rule, for example, may also involve a deviation from what is acceptable (the practice is unsafe), but not from what is regarded as normal by the worker's workgroup (i.e., it is a cultural norm of the workgroup). *Normal violations* are not unsafe in the eyes of the operator but are accepted as normal ways of working within the group; however, *anomalous violations* are not appropriate behaviors (although they might serve a variety of purposes for the operator, for example, saving time or effort, relieving boredom or testing skills) as they are unacceptable and potentially unsafe (Clarke, 1994). The Clapham Junction disaster was triggered by the actions of a worker undertaking maintenance work of the signaling system; as highlighted in Summary Text 8.8, his actions included both normal and anomalous violations that were critical etiological components of the subsequent disaster. Strongly held norms can be

---

SUMMARY TEXT 8.8 Clapham Junction Rail Crash

A collision occurred among the 18:18 Basingstoke to Waterloo train, the 06:14 Poole to Waterloo train, and a train of empty coaches southwest of Clapham Junction Station at about 08:10 on December 12, 1988. Thirty-five people were killed and many others injured.

A new signal had malfunctioned, so that the second train was not prevented from occupying the same track as the earlier one and failed to stop the front of the second from running into the back of the first. The driver of the first train had seen the signal change from green to red as he passed it and was obliged to stop and report a signal passed at danger (SPAD). He could not have known that the signal was faulty and that following trains had not also been stopped. The immediate cause of the faulty signal was false feed of current from an old wire in the Clapham Junction relay room. This situation was the result of electrical work done on two separate occasions within the previous 2 weeks. On the first occasion, the senior technician responsible for the work violated procedures in not cutting back the old wire but merely bending it away. The supervisor, who was involved in other work, had not inspected the senior technician's work. The second job, undertaken coincidentally by the same senior technician, compounded the initial violation as the old wire reverted to its original position when a new relay was being installed. However, the inquiry also identified responsibility among many other parties who had allowed a situation in which such errors could be made and remain undetected when such work was inspected, tested, and commissioned back into service. The supervision and monitoring of poor working practices was criticized for its inadequacy. Malpractice was found to be widespread, indicating a lack of adequate staff training. Management was criticized for incompetence, ineptitude, inefficiency, and failure (p. 73). Lessons from previous incidents had not been learned and it was concluded that "concern for safety was permitted to coexist with working practices that were positively dangerous." This unhappy coexistence was never detected by the management and so the bad practices were never eradicated (p. 163). Ninety-three separate recommendations were made.

Source: Great Britain: Department of Transport, *Investigation into the Clapham Junction Railway Accident*. Anthony Hidden QC, Cm 820, HMSO, London, 1989.

---

maladaptive where they lead to normative and highly routinized behavior, which is rarely questioned, while at group level a team's ability to develop novel solutions, adapt to changing performance demands and maintain long-term learning can be damaged (Tesluk & Quigley, 2003).

Coworker safety norms have been examined in relation to employee risk-orientation and risk-taking behavior. Watson, Scott, Bishop, and Turnbeaugh (2005) found that coworker safety norms were significantly predictive of employees' at-risk behavior; furthermore, Westaby and Lowe (2005) found that coworker norms were more influential in predicting the risk-orientation of young workers than were supervisory norms. Coworker safety norms are not only important in relation to risk-taking behavior, but also act to encourage proactive safety behaviors (Fugas, Silva, & Meliá, 2012, 2013).

8.2.2 Theory of planned behavior

The influence of group norms, in the form of the *subjective norm*, is incorporated into the Theory of Planned Behavior (TPB), which predicts an individual's behavior, taking into account the individual's attitudes, beliefs, and intentions. This social-psychological theory was first developed as the Theory of Reasoned Action (TRA) and was later adapted as the Theory of Planned Behavior (Ajzen, 1985; Fishbein & Ajzen, 1975). The TPB extends the TRA model, by the addition of an individual control component that is influenced by the person's evaluation of factors likely to inhibit or facilitate their performance of the behavior (Ajzen, 1991). The TPB model (shown in diagrammatic form in Figure 8.1, incorporating a safety example) argued that behavior can be predicted if we know

- The individual's attitude to the particular behavior
- The individual's intention to perform that behavior
- What he or she believes are the consequences of performing that behavior
- Social norms (socially acceptable behavior) which govern that behavior

Behavior is predicted by behavioral intention, which in turn is determined by a combination of three factors: attitude to the behavior (the individual's attitude toward performing the behavior); subjective norm (the individual's perception of the normative pressure to perform the behavior); and perceived behavioral control (the individual's perception of the degree to which performing the behavior is under his or her volitional control). An individual's attitudes are determined by two factors: the individual's beliefs about the consequences of the behavior, both positive and negative (behavioral beliefs), and the individual's evaluations of those outcomes (outcome evaluations). The influence of subjective norms is determined by the individual's perceptions of the extent to which significant others think he or she should engage in the behavior (normative beliefs) and his or her motivation to comply.

The TPB model has been expanded (e.g., Manstead & Parker, 1995) and tested extensively in relation to driver behavior. For example, Parker, Manstead, Stradling, Reason, and Baxter (1992) demonstrated the ability of the TPB model to predict driving violations in a sample of 881 motorists. Interestingly, the influence of the social context, in the form of subjective norms, was more powerful in predicting behavioral intentions, compared with the individual's own attitudes to the behavior. In the case of behaviors that are antisocial or attract social disapproval, it has been suggested that personal norms are also influential. Parker, Manstead, and Stradling (1995) examined the impact of adding the variables anticipated regret and moral norm to the prediction of motoring violations (including cutting

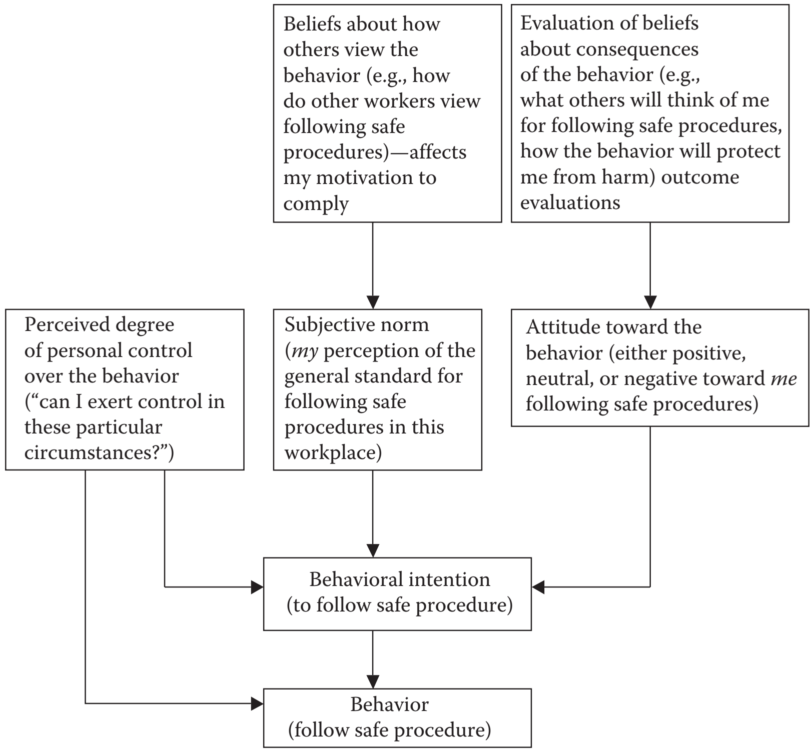


Figure 8.1 Theory of planned behavior. (After Ajzen, I., From intentions to actions: A theory of planned behavior, in: Kuhl, J. and Beckman, J. (eds.), *Action–Control: From Cognition to Behavior*, Springer, Heidelberg, Germany, 1985, pp. 11–39; Ajzen, I., *Organ. Behav. Hum. Decis. Process.*, 50(2), 179, 1991; Fishbein, M. and Ajzen, I., *Belief, Attitude, Intention and Behavior: An Introduction to Theory and Research*, Addison–Wesley, Reading, MA, 1975.)

across traffic to leave a highway and overtaking on the inside). The study illustrated that in each case adding these variables significantly improved the ability of the model to account for the behaviors. Parker, Lajunen, and Stradling (1998) studied the role of affect in the commission of aggressive driving behavior in two scenarios: one in which the respondent is described as retaliating to aggressive behavior on the road (deliberately slowing down a car behind you that is tailgating and flashing its headlights); and the second, where the respondent is described as initiating a "road rage" incident (giving chase to a car that has cut in front of you, forcing you to brake sharply, and gesticulating/verbally abusing the driver). In both cases, consideration of affective beliefs predicted behavioral intentions over and above the elements of the TPB model. Overall, beliefs and attitudes toward retaliatory aggressive driving accounted for 30% of the variation in committing aggressive violations. Those who reported relatively high levels of retaliatory "road rage" had more positive attitudes toward aggressive driving, perceived more social support for aggressive driving, experienced greater feelings of positive affect and less control, in terms of being able to refrain from retaliating behavior. Although affect accounted for a small but significant proportion of the variance, the key psychological variable was perceived behavioral control. The TBP model, including affective beliefs, was most significant in predicting aggressive violations in relation to beliefs and attitudes toward initiating "road rage," where 40%

of the variation was predicted. This may reflect the more considered nature of initiating an aggressive act (i.e., more deliberately planned), compared with being provoked to respond to aggressive behavior from others.

The TPB model has been used as a theoretical framework for investigating safety-related behavior in work settings. Johnson and Hall (2005) applied the TPB model to explain safe-lifting behavior in a U.S. manufacturing plant; they found that the model was significantly predictive, and that subjective norms had an important influence on safe practice (although the most influential aspects of the TPB were perceived behavioral control and behavioral intentions). Subjective norms were also found to predict employees' intentions to violate safety rules and actual violations (Fogarty & Shaw, 2010). Fugas et al. (2013) found that strong coworker norms and perceived behavioral control distinguished between groups of workers with the best profile for workplace safety behaviors (although as in Fogarty and Shaw's study, perceived behavioral control was most influential).

The role of other variables, such as previous behavior, frequency of the behavior, and habituation, has been the subject of debate. There is evidence to suggest that the use of models such as TPB is less powerful in predicting high-frequency behaviors that demonstrate habituation responses. For example, Knapper, Copley, and Moore (1976) investigated attitudes toward car safety belts, the results indicating an overwhelming tendency for respondents to express positive attitudes toward the use of seat belts and confidence in their effectiveness; yet these attitudes existed irrespective of whether respondents claimed to use seat belts. A significant finding was that the main factor responsible for claims by respondents that they were using seat belts was not simply a matter of having a positive or negative attitude, but was predominantly governed by the habit of using a seat belt. Similarly, Verplanken, Aarts, Van Knippenberg, and Van Knippenberg (1994) when examining choice of travel mode (car versus train) found that the attitude–behavior link was weak when habitual behavior was strong, and conversely, that attitude was only a good predictor of behavior when habit was weak, suggesting that habit strength moderated the attitude–behavior relationship. Another example, which may well extend to compliance with safety rules and regulations, is drivers' compliance with speed limits. Åberg, Larsen, Glad, and Beilinson (1997) found that more than 50% of drivers in their study exceeded the speed limit, and a majority of them overestimated the speed of other drivers. Perceptions of other drivers' speeding, as well as attitudes toward speeding, were significant predictors of exceeding the speed limit. In their study of 598 drivers, Elliot, Armitage, and Baughan (2003) illustrated the moderating effects of habitual behavior by finding that prior behavior moderated the perceived control-intention and perceived control-subsequent behavior relationships.

8.3 Organizational safety climate

Individual and group behavior is influenced by the broader context within which the behavior takes place; these broader contextual factors are often underplayed and their impact not fully understood (Johns, 2006). In relation to understanding safety behavior, both at an individual and a group level, *organizational safety climate* has emerged as a powerful contextual influence. Considerable research has focused on the effect of safety climate, both as an organizational-level and a group-level construct.

Zohar's (1980) definition of safety climate stated that climate can be viewed as "a summary of molar perceptions that employees share about their work environments" and that "these perceptions have a psychological utility in serving as a frame of reference for guiding appropriate and adaptive task behaviors" (p. 96). Safety climate is conceptualized as a facet-specific form of organizational climate; such that safety climate is a specific construct that relates to employees' perceptions of the work environment in relation to safety. This conceptualization recognizes that an organization may have multiple climates, each with a specific referent, e.g., a climate for service, or a climate for safety (Schneider, 1990; Schneider, White, & Paul, 1998). In support of this view, Neal, Griffin, and Hart (2000) examined effects of workers' perceptions of the organizational climate (i.e., appraisal and recognition, goal congruency, role clarity, supportive leadership, participative decision-making, professional growth, and professional interaction) and their perceptions of the safety climate (i.e., management values, communication, training, and safety systems); their findings suggested that the influence of organizational climate was completely mediated by safety climate, as organizational climate did not contribute to performance once safety climate effects were partialled out.

In a later definition, Neal and Griffin (2004) defined safety climate as "perceptions of the policies, procedures and practices relating to safety [which at the broadest level reflect] … employee perceptions about the value of safety in an organization" (p. 18). Although Zohar (1980) defined safety climate in terms of shared perceptions, other work tended to view employees' perceptions as an individual-level variable. For example, Dedobbeleer and Béland (1991) noted that, "employees were believed to develop coherent sets of perceptions and expectations regarding behavior-outcome contingencies and behaving accordingly . . . safety climate was viewed as an individual attribute as opposed to an organizational attribute" (p. 97). At the individual level, safety climate aligns with the definition of psychological climate, which refers to individual perceptions (James & Jones, 1974). Measurement of safety climate as an organizational construct is usually based on the aggregation of individual-level responses.

8.3.1 Structure of safety climate

Safety climate is a multidimensional construct that reflects employees' perceptions of their work environment in relation to safety. Griffin and Neal (2000) argued that safety climate can be represented as a model which comprises a single second-order (or global) factor and a set of first-order factors (reflecting different aspects of the work environment). The first-order factors identified in empirical studies has varied in number and content (Clarke, 2000). In a review, Flin, Mearns, O'Connor, and Bryden (2000) were able to identify five dominant themes that were common across studies:

1. *Management/supervision*: Perceptions of management safety attitudes and behaviors (relative to other issues, such as production)
2. *Safety system*: Perceptions of (or satisfaction with) the efficacy of the organization's safety management system (including safety policies)
3. *Risk*: Perceptions of risk/hazards in the workplace or attitudes toward risk and safety
4. *Work pressure*: Factors relating to work pace or workload (reflecting the balance of safety and production goals)
5. *Competence*: Perceptions of employees' safety knowledge and skills (including related aspects such as selection and training)

The literature seems to suggest that there is some stability in factor structure across plants within the same multinational organization in different countries (Cheyne, Cox, Oliver, & Tomás, 1998; Janssens, Brett, & Smith, 1995), and within the same country across similar industrial sectors (Varonen & Mattila, 2000). However, there is a strong influence from industry type, as dimensions vary due to the method of questionnaire development, which reflects issues pertinent to a particular organization or industry sector. Variations in physical hazards, work environment, teamworking, prevalence of written rules and regulations, style of management, intensity of supervision, and prominence of safety representatives, are among organizational features likely to be reflected in safety climate measures. Glendon and Litherland (2001) found differences between job types, but not between districts, on two of six safety climate factors: relationships and safety rules. The authors hypothesized that differences were due to varying work environments (particularly level of supervisor contact and degree of formalization). Zohar (2010) has argued that while generic measures of safety climate (which focus on common themes, such as management commitment to safety) can be used across industries, there remains value in measuring industry-specific aspects of safety climate. Empirical studies have demonstrated the added value of including industry-specific as well as generic items in safety climate measures in the trucking industry (Huang, Zohar, Robertson, Garabet, Lee et al., 2013) and for electrical workers (Huang, Zohar, Robertson, Garabet, Murphy et al., 2013).

8.3.2 Multilevel model of safety climate

Safety climate models have positioned safety climate as a mediator in the relationship between organizational climate and safety outcomes (Clarke, 2010; Wallace, Popp, & Mondore, 2006). Empirical studies have supported such a mediation role (Brondino, Silva & Pasini, 2012; Griffin, Neal, & Rafferty, 2002; Neal et al., 2000; Zohar, 2002a), in which safety climate mediates the relationship between organizational climate (Neal et al., 2000), leadership style (Zohar, 2002b), and local leadership (Griffin et al., 2002) on measures of safety performance. Zohar and Luria (2005) tested a multilevel model of climate, in which group safety climate mediates the effect of organizational safety climate on employees' safety behavior. This model is based on a "level-of-analysis interpretation of climate as convergent, level-adjusted perceptions or appraisals of relevant policies, procedures, and practices as indicators of desired role behavior" (p. 616). Therefore, the model proposes that employees develop perceptions of organizational policies and practices, which are interpreted at a local level; this involves a sense-making process as employees may encounter a multitude of sometimes conflicting information regarding the importance of safety. At the organizational level, the referent for employee perceptions is top management, while at a group level, the referent is the supervisor. Zohar and Luria used multilevel analysis to test this hypothesized model with a large sample of 401 workgroups nested in 36 small- and medium-sized manufacturing organizations. Using multilevel modeling, the authors found support for the model as organizational climate effects were fully mediated by group safety climate. However, it is difficult to replicate this model as the dataset required is very large, with particular constraints in gaining sufficient numbers at the higher levels (i.e., number of organizations and nested workgroups).

8.3.3 Safety climate as a leading indicator

Research has linked a more favorable safety climate with positive safety-related outcomes (Beus et al., 2010; Clarke, 2006, 2010); for example, a positive safety climate might actively encourage and support employees in making safety suggestions, while in a negative safety climate, employees might observe that safety suggestions are dismissed or discouraged. Where perceptions of safety climate are more favorable (indicating a positive safety climate), workers are less likely to engage in unsafe acts (Hofmann & Stetzer, 1996), to have suffered an injury (Brown & Holmes, 1986; Mearns, Flin, Gordon, & Fleming, 1998; Varonen & Mattila, 2000; Williamson, Feyer, Cairns, & Biancotti, 1997), or have subsequent injuries (Huang et al., 2012; Johnson, 2007). There is also evidence that a positive safety climate maintains safety-related organizational citizenship behaviors including involvement in safety activities (Cheyne et al., 1998) and safety participation (Neal et al., 2000). Longitudinal studies have supported the directionality of the relationship, such that safety climate influences safety behavior and subsequent injuries (Johnson, 2007; Neal & Griffin, 2006). However, there is also evidence of a reciprocal link, such that safety outcomes also impact on the safety climate over time (Beus et al., 2010). The evidence that safety climate reliably predicts subsequent safety-related behavior and safety outcomes, including accidents and injuries, has led to the popularity of safety climate perceptions as a "leading indicator" of organizational safety. Thus, employee perceptions of safety climate provide a reliable indicator of the current state of safety, in preference to "lagging indicators," such as accident and incident rates.

8.4 Group safety climate

Research has increasingly recognized that shared perceptions of the priority given to safety exist at the group level (Zohar, 2000). Group-level safety climate can be different from the organizational safety climate and differ between groups (Zohar, 2000; Zohar & Luria, 2005), leading to the existence of distinctive *subclimates* associated with different workgroups.

8.4.1 Group safety climate as a function of supervisory action

Researchers have focused on group-level safety climate (Zohar, 2000, 2002a), where climate is defined in terms of how supervisors prioritize safety issues. This work suggests a top-down influence on the development of shared safety perceptions within groups. Zohar (2000) argued that workgroups develop distinct subclimates due to differing levels of supervisory commitment to safety. Zohar and Luria (2004) found that supervisory practices (which indicate the priority of safety) act as an antecedent to the emergence of group safety climate. The definition of group safety climate uses supervisory emphasis, in terms of safety, as the referent for employees' perceptions, referring to supervisory "practices-as-pattern" in relation to the whole group, rather than isolated supervisory actions. Zohar found that two factors emerged that were identified as supervisory action and expectation: the former refers to overt supervisory reaction to subordinates' conduct (i.e., positive and negative feedback) and initiating action concerning safety issues, while the latter refers to expectations, mostly in relation to safety issues versus productivity. Later research found that a three-factor model demonstrated improved fit, which comprised caring, coaching, and compliance practices (Johnson, 2007; Zohar & Luria, 2005). Zohar and Luria (2005) found that between-group variation within an organization can be explained by differences in supervisors' interpretation and implementation of organizational safety policies and procedures. There is evidence that supervisors' response to the organizational safety climate affects the strength of the group safety climate, such that supervisors who demonstrate a positive leadership style promote greater consensus of employees' safety perceptions at a group level (Zohar & Luria, 2010). This would suggest that supervisors act as "gatekeepers" in that they interpret organizational policies and practices for their workgroup; for example, if the organizational safety climate fails to emphasize safety, the supervisor places greater emphasis on safety at a local level to ensure the well-being of his or her group members. In addition, due to their position, supervisors may have access to observe senior managerial actions in relation to safety policies and practices and therefore develop their own interpretation of the organization's safety priorities (Huang et al., 2014).

There is evidence to suggest that a group safety climate (supervisory action and expectation) influences safety outcomes, including accidents and injuries (Christian, Bradley, Wallace, & Burke, 2009; Zohar, 2000) and safety performance (Johnson, 2007). For example, Guest, Peccei, and Thomas (1994) found that (in comparison to high-injury workgroups) low-injury workgroups had supervisors who were more concerned for their workers, made the staff feel valued, kept them informed, and treated them fairly. Johnson (2007) found that a group safety climate predicted safe behaviors (observed subsequently for more than a 5-month period) and injury rates (based on objective records). Further evidence comes from safety interventions which have targeted improvements at supervisory practices. For example, Zohar (2002b) found that enhancements to supervisory safety practices resulted in strengthening the safety climate and reducing subunit injury rate. Zohar and Polachek (2014) implemented a feedback intervention in which supervisors in the experimental group received feedback on their safety exchanges, while those in the control group received no feedback; they found that team members of supervisors in the experimental group reported a significantly improved safety climate and safety performance (12 weeks after the intervention).

Group safety climate has an important influence on how group members respond to safety messages from the organization. For example, Luria and Rafaeli (2008) found that group safety climate affected how employees interpreted safety signals, such that workgroups with a positive safety climate tended to interpret safety signals more favorably (as reflecting the organization's commitment to safety) whereas those workgroups with a negative safety climate tended to interpret safety signals less favorably (as reflecting organizational compliance with safety regulations). This finding would suggest that organizational safety initiatives are likely to have differential effects dependent on the level of group safety climate. Group-level climate also acts as a moderator in the relationship between employees' safety knowledge and their behavior (Jiang et al., 2010); this would suggest that the extent to which safety training is effective will depend on the local safety climate.

8.4.2 Group safety climate as an emergent property of the team

Coworkers act as an important social referent for their fellow employees' behavior (Chiaburu & Harrison, 2008), meaning that employees frequently look to their fellow workers for social cues regarding appropriate behavior. There is evidence that employees' response involves making attributions about their coworkers which results in changes to their behavior (Lepine & Van Dyne, 2001). Furthermore, employees evaluate their own standing against their coworkers and determine the appropriate degree of reciprocation, such as engaging in helping behaviors in the workplace (Takeuchi, Yun, & Wong, 2011). The influence of coworkers is significant, over and above the effect of formal leaders, such as supervisors, on employee behavior (Pearce & Sims, 2002). The workgroup also has the most powerful socialization effect on new workers (Moreland & Levine, 2001).

The general literature on coworker influence suggests that it has a substantial effect on employee behavior. In terms of workplace safety, coworkers are likely to have frequent interactions with each other, and to discuss and compare experiences related to safety. Interactions are likely to be frequent not only due to proximity, but also due to coworkers tending to have similar hierarchical status and to experience a similar working environment, leading to a high degree of identification between coworkers. Such interactions may form part of a sense-making process at the group level, where individuals discuss their own experiences and compare these to others, in order to aid their interpretation of company safety policies and practices, and the relative importance given to safety (Luria, 2008; Zohar & Tenne-Gazit, 2008). Thus, group-level norms and expectations regarding safety-related behavior develop as an emergent property of the group. Such a process can account for differences in group-level safety climate between teams, especially in decentralized organizations where the nature of the work is nonroutine, such as construction (Lingard, Cooke, & Blismass, 2009). Turner, Chmiel, Hershcovis, and Walls (2010) argued that coworkers act as an important source of safety information and that social cues from coworkers can reinforce the message that safety is prioritized. In their study, the authors found that support from coworkers played a significant role in attenuating the adverse effects of job demands on the occurrence of hazardous work events; the effect from coworkers was stronger than the effect from supervisors and managers, and occurred over and above these leadership effects (Turner et al., 2010). Thus, in situations characterized by high demands, employees rely more on the support of their coworkers than that from supervisors or managers. Lingard, Cooke, and Blismass (2010) investigated the effect of shared perceptions regarding coworker safety (i.e., that coworkers should give safety a high priority in their work) within workgroups in construction; they found that those workgroups in which group members shared a strong consensus regarding coworker safety had significantly fewer occupational injuries compared to other workgroups.

A number of studies have found that group processes are linked to safety climate (Cheyne et al., 1998; Hofmann & Stetzer, 1996; Luria, 2008; Tucker et al., 2008); and, furthermore, that group processes act as an important antecedent in the development of safety climate (Clarke, 2010; Zohar & Tenne-Gazit, 2008). Luria (2008) argued that highly cohesive groups engaged in frequent social interactions within the group and therefore were more likely to form greater shared consensus about the priority given to safety (i.e., higher level of climate strength). Cohesion was found to lead to higher levels of climate strength; in addition, cohesion moderated the relationship between passive leadership and climate strength, and accentuated the relationship between transformational leadership and climate strength (Luria, 2008). This would suggest that highly cohesive groups formed a consensus about safety based on social interactions within the group, even when their leaders were indifferent to the importance of safety; furthermore, group cohesion enhanced the effects of positive leadership on climate strength. Zohar and Tenne-Gazit (2008) examined the social interactions that underpin cohesion within workgroups using social network analysis; they found evidence that both communication and friendship networks played an important role in the development of shared perceptions regarding safety (climate strength). Communication density (i.e., the proportion of employees exchanging work-related information) was found to promote higher consensus of climate perceptions (climate strength); friendship density (i.e., the extent to which employees establish direct personal relationships, in which they compare themselves to each other) was also directly related to climate strength. These effects of social interaction were found to exist over and above the effects of leadership. Communication density mediated the effect of leadership, such that leadership influenced the degree of safety-related communication with workgroups, but friendship density had independent additive effects (showing that the influence of friendship within groups was unrelated to leadership). Therefore, there are likely to be two pathways for the influence of coworkers: (1) they can help other employees to interpret safety messages at a local level (by mediating the effect of leadership on safety behavior), and (2) they can affect other employees' behavior directly through personal influence.

The relative influence of supervisors and coworkers has been examined in a number of studies, which have found mixed results. For example, Brondino et al. (2012) found that employees' perceptions of coworkers' safety priority had a stronger effect on safety behavior than did their perceptions of supervisors' safety. In their meta-analysis, Nahrgang et al. (2011) demonstrated that both coworker social support and supervisor social support had a significant association with safety outcomes, but that the strength of the relationship depended on the type of outcome. They found that coworker social support had a stronger effect on occupational accidents and injuries and adverse safety events, but that supervisor social support had a stronger effect on safety-related behavior. Other studies have found interaction effects, suggesting that the two variables have a combined effect on safety. Jiang et al. (2010) found that positive perceptions of coworkers' safety behavior (i.e., that coworkers act as behavioral role models for safety) was associated with employees' own engagement in safety behavior only in combination with high unit-level safety climate. Yagil and Luria (2010) examined the effects of group-level safety climate and quality of relationships with coworkers (e.g., coworkers give me sound advice) on employees' safety compliance. The authors found that high-quality relationships increased the level of safety compliance in combination with low safety climate, such that high-quality relationships with coworkers may act as a buffer against the negative effects of a poor safety climate on safety behavior. The varying interaction effects would suggest that the relative influence of supervisors and coworkers on safety will depend on other situational factors, which have yet to be investigated.

8.4.3 Group safety climate and trust

There has been a tendency to consider consistency of safety climate perceptions both within groups and between groups as desirable for ensuring safety. Indeed Zohar, Livne, Tenne-Gazit, Admi, and Donchin (2007) found that alignment between organizational and group safety climates was associated with better safety outcomes. However, it may be argued that differences both between and within groups in terms of safety climate may act to stimulate reflection on safety practices and help discourage complacency. Even at an intra-group level, a degree of skepticism and conflict may be beneficial to maintaining a positive safety climate (despite an emphasis on shared attitudes and beliefs). Jehn (1995) demonstrated that task conflict (disagreements about task content) promoted critical evaluation of problems and consideration of different options when performing nonroutine tasks. Task conflict can have positive benefits for team performance; Bradley, Postlethwaite, Klotz, Hamdani, and Brown (2012) found that psychological safety moderated the relationship between task conflict and team performance, such that under conditions of high psychological safety, task conflict led to improved team performance. Similarly, "healthy" skepticism about safety may help to maintain a general alertness among the workforce toward potential safety problems. Burns, Mearns, and McGeorge (2006) found that employees had implicit trust in their coworkers (i.e., attitude could be automatically activated), but only explicit trust in their managers and supervisors (i.e., attitude could not be automatically activated). This finding suggests that direct effects of coworkers on employee behavior might be underpinned by the implicit trust that employees have in their coworkers. However, based on a literature review and small interview study, Conchie and Donald (2008) suggested that interpersonal trust should be moderate, and that high interpersonal trust could have detrimental effects on safety by increasing exposure to safety incidents (e.g., employee trusts a coworker's word that a safety procedure has been followed, rather than checking for him or herself). This level of "distrust" recognizes that even trusted individuals can make mistakes.

8.5 Managing effective work teams

Many disasters have occurred due to failures of teamwork, such as miscommunication between the flight deck and the rest of the crew (e.g., Kegworth air disaster, see Summary Text 8.1), and "groupthink" in decision-making bodies (e.g., *Challenger* shuttle disaster, see Moorhead et al., 1991). However, evidence suggests that well-designed and well-managed teams contribute positively to organizational safety.

Referring to evidence that increased teamworking can lead to productivity increases within organizations, Hackman (1994) warned that building effective teams is not easy and that it may be possible to obtain similar improvements in other ways. He also cautioned that using teams is not an easy solution and that if carried to its logical conclusion, could well represent a revolutionary threat to the established management order. Nevertheless, teamworking is now well established across industries, with many teams responsible for operating in safety-critical situations; indeed some safety-critical tasks can only be effectively delivered by teams. Therefore, the ability to effectively manage teams is essential to maintaining safety in many organizations. Although there is evidence that the use of teams, in particular those that are self-managing, will benefit safety (Hechanova-Alampay & Beehr, 2002; Pearson, 1992; Roy, 2003), potential threats to developing a positive group safety climate need to be managed carefully.

A performing unit may be called a team but is often managed as a set of individuals; for example, with respect to work allocation, reward, selection, and appraisal. It is important that group processes operate effectively within teams; that is, that team members work interdependently to develop strong group norms and group cohesion. Managing a unit as a set of individuals will serve to undermine group characteristics that lead to enhanced performance. Effective group processes create a team climate in which there is a sense of belonging that allows members to speak up, suggesting alternative ways of working and admitting to mistakes (Edmondson, 1999), as well as enabling development of safety citizenship behaviors, such as approaching coworkers engaged in unsafe acts (Hofmann, Morgeson, & Gerras, 2003; Hofmann & Stetzer, 1996). Team leaders need to facilitate team functioning by encouraging members to speak up, creating opportunities for learning, and promoting openness in communication (Edmondson, 2003). Salas, Cooke, and Rosen (2008) argued that team cognition (i.e., shared mental models, team situation awareness, and communication) is essential for effective team performance. Indeed, in a meta-analysis, DeChurch and Mesmer-Magnus (2010) found substantial effect sizes for the relationship between aspects of team cognition and team effectiveness.

In terms of safety, feelings of empowerment are particularly important in determining the success of autonomous teams: those teams with greater empowerment engaged in fewer unsafe behaviors and had fewer injuries (Hechanova-Alampay & Beehr, 2002). It is important to specify a team's ends or objectives but also to allow the team to determine the means for achieving their objectives. This shows that specifying neither the means nor the ends (complete democracy) can result in an anarchic state in which the team has no *raison d'être*. However, specifying both means and ends (extreme authority) is also a poor team management strategy because the team has no autonomy or opportunity to display creativity in achieving its objectives, thereby representing a waste of human resources. However, worse still is to prescribe the means (e.g., parameters and mode of operation) but not to give the group any indication of its ultimate objective. This is liable to leave the group frustrated and de-motivated. The best option is to provide a group with its objective and leave the members to determine how to achieve it. This is most likely to result in an active search for solutions that involve group members in enjoyable and effective problem solving. Many "outward bound" team-building exercises are designed on this principle. The irony of such exercises is that while they are designed to develop teamwork, frequently they are used to identify individuals for development or promotion within an organization, for which there is no evidence of their validity. Other criteria to be aware of include: maintenance of group member interrelations and ability to solve future problems, as well as using groups to improve member motivation. It should be acknowledged that team members can reliably be left to work things out for themselves and that the organization's role should be to provide an enabling structure. However, it is a common failing that once formed, teams are left unsupported. What is required are: rewards for the team not for individuals, adequate material resources, a system to provide relevant information to the team, and a supportive educational program.

Advances in team training mean that this can be highly effective in improving team performance. Crew resource management, which focuses on the development of team skills such as assertiveness, maintaining shared situation awareness, and communication, has proven an effective means of increasing team performance in safety-critical teams, such as aviation (Salas, Fowlkes, Stout, Milanovich, & Prince, 1999). The use of simulator training is also increasingly utilized to develop safety-critical teams, such as emergency response teams (Wheeler, Geis, Mack, LeMaster, & Patterson, 2013).

8.6 Conclusions

Group discussion is held to have a number of benefits for group functioning and for individual member satisfaction. However, for some types of problems, suitably able and qualified individuals acting alone may make better decisions. In any case, it is important to select the right type of group for the task to be undertaken. While there is strong pressure to conform to group norms, there are always likely to be those who will resist group pressure. This may be a positive asset if nonconformity brings new approaches to tasks or leads to the identification of risks that others have overlooked. However, it is not likely to be acceptable in circumstances in which group norms are positively related to safety. Group norms and expectations can have powerful effects on individuals' behavior (e.g., the role of the subjective norm in the TPB) and underpin the development of safety climate at the group level. Research has demonstrated that the relationship between safety climate and safety outcomes is stronger at a group level, than at an individual level. Group processes, such as communication and cohesion, are important for ensuring safety. Cohesive groups, which develop a higher level of psychological safety, better enable the monitoring of group members' work and the recovery of errors, speaking up and making safety suggestions. However, highly cohesive groups are also vulnerable to groupthink.

Groups may not follow an ideal route in making decisions, falling prey to such dysfunctional outcomes as groupthink, which could produce disastrous results, particularly in cases where decisions involve high risks. To overcome this type of failure and to increase the effectiveness of group decisions, it is important to build in procedural audits of the quality of decision making and to ensure heterogeneity of personal styles and roles within a group. Various studies suggest that in making decisions of various kinds, groups tend to see responsibility for decision outcomes to be shared among group members. This may result in groups making riskier decisions than individuals acting alone. Some decisions are best made by individuals, perhaps in consultation with others, while in other cases groups offer a superior decision-making forum. It is possible to adopt a logical approach in deciding whether to use a group or an appropriate individual to make any given decision.

From an evolutionary perspective, cooperative kinship and wider community groups provided security for our ancestors, thereby reducing risks from predators, and competing groups as members could look out for one another's interests. However, a potential downside of group membership is that members might falsely believe that others were looking out for them; an early example of "social loafing." Such a dichotomized model might underlie several of the phenomena described in this chapter, including groupthink and other failures in decision making, as well as differences between group and individual-level findings on safety issues. The strong evolutionary imperative to bind with recognized primary group members, which predates larger organizational forms, might also account for the threat from autonomous workgroups (self-managed teams) to organizational hierarchies, especially in relation to safety-critical operations. Nevertheless, there are clear benefits of shared leadership within teams, both in terms of team performance and safety outcomes.

While there has been some debate concerning the effectiveness of teams (e.g., Allen & Hecht, 2004), when well-managed, evidence suggests that teams have many positive benefits for organizational safety. Team effectiveness requires a variety of conditions to be met. Thus, teams need to be well designed in terms of their task, composition, and norms. They should also have bounded authority so that objectives are specified, but not detailed means to achieve them, allowing team members a degree of autonomy or "empowerment." Teams should be motivated through having a clear, engaging direction. There should be a supportive organizational context in terms of rewards, resources, and education, as well as expert coaching available.

While there are various ways of assessing group performance, it is generally accepted that there are two broad areas of group functioning. The *task* area deals with substantive topics, and the *socio-emotional* area is relevant to procedures and member interrelations. Both are important and can be assessed in various ways: for example, sociometry (for examining member interrelations), beating the competition (for determining task effectiveness), and interaction process analysis (to evaluate interactions across both areas). One problem associated with conducting quantitative research on teams is that many studies are based on small samples, which lead to reduced statistical power, making it difficult to draw reliable conclusions. It is also rare to find studies examining the impact of organizational variables on group processes (and, in turn, on individual-level behavior), using techniques such as multilevel analysis.

chapter nine

Safety leadership

This chapter discusses the role of leaders and leadership style in relation to organizational safety. We review research evidence, relevant leadership theories, and explore some implications for improving safety through leadership development and training. While it is beyond the scope of this chapter to provide a comprehensive review of leadership theories, we focus on those that have provided theoretical and empirical insights into the role of leadership in organizational safety (for a detailed review of leadership theories, see Barling, Christie, & Hoption, 2011). The chapter begins by reviewing concepts and theories of leadership; it then discusses the impact of leadership on safety performance, relevant psychological mediators and moderators, and managing leadership roles to reduce risk and improve organizational safety through leadership development, training, and other interventions. While it would be interesting to study facets of leadership under extreme (e.g., armed combat) conditions, the chapter contents reflect the fact that virtually all research into safety leadership has been conducted in organizational settings.

While early investigations into accident causation tended to focus on individual and technical antecedents (e.g., human error, equipment failure), increasingly such investigations have recognized the involvement of organizational and systemic factors, which highlight the role played by managers, board members, designers, and others (Reason, 1997). This shift in understanding accident causation extends the timeframe to include several agents not present when an incident occurs, but who nonetheless contributed to its occurrence. Reason (1993) suggested that a majority of organizational accidents, ". . . have their origins within the managerial and organizational spheres . . ." (p. 8). Major disaster analyses often confirm this attribution (e.g., Hopkins, 2000, 2008, 2012; McInerney, 2005). For example, the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (2011) report into the Macondo accident in 2010 concluded that: ". . . most of the mistakes and oversights at Macondo can be traced back to a single overarching failure – *a failure of management.* Better management by BP, Halliburton, and Transocean would almost certainly have prevented the blowout by improving the ability of individuals involved to identify the risks they faced, and to properly evaluate, communicate, and address them" (p. 90; emphasis added).

Strategic decision making within an organization affects the allocation of resources and personnel, reflecting the extent to which safety issues are taken into consideration. An examination of such decisions is often contained within accident investigations; for example, Lord Cullen's report into the 1988 Piper Alpha disaster (Cullen, 1990) identified the failure to install blast walls as a contributory factor in the accident. The less-effective (but less expensive) option of installing firewalls had been taken some years before the accident. Twenty years later, another disaster in the oil and gas industry illustrated how business decisions continued to impact accident etiology (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, 2011)—see Summary Text 9.1.

A long tradition of leadership research has established the key role that leaders play in promoting workplace safety (Cohen, 1977; Dunbar, 1975; Hofmann, Jacobs, & Landy, 1995).

SUMMARY TEXT 9.1 The 2010 *Deepwater Horizon* Accident

The *Deepwater Horizon* was a semi-submersible oil drilling rig (owned by Transocean and leased to BP) in the Gulf of Mexico. On April 20, 2010, an explosion on the rig caused by a well blowout led to the deaths of 11 crewmembers and a major oil spill into the Gulf of Mexico. The incident occurred as the *Deepwater Horizon* rig crew were preparing the Macondo well for temporary abandonment. Work on the well was significantly behind schedule and there was a substantial cost overrun. During the final phase of abandonment, the driller was responsible for monitoring the well, with additional assistance from the mudlogger. Well monitoring is a critical activity, as quick detection of hydrocarbons flowing from the well (known as a "kick") is essential to shutting in the well successfully. The actions of the rig crew meant that they were not able to monitor the well effectively and were dependent on checking the drill pipe pressure as an indicator of flow. Although there were indications that the drill pipe pressure had spiked, suggesting a kick had occurred, these were missed by the rig crew, as they were distracted by other activities involved in abandoning the well quickly. Due to the delay in detecting the kick, the crew were too late shutting in the well. Hydrocarbons flowed onto the rig, leading to a massive explosion. Prior to the Macondo incident, there had been previous incidents of undetected kicks on the *Deepwater Horizon*. On March 8, 2010, the same crew was involved with an incident where there was a delay in kick detection of 33 minutes before the well was shut in. BP conducted an investigation into this well control event and delivered verbal feedback on "lessons learnt" to BP and Transocean personnel on the rig, but there was no evidence that specific action had been taken as a result.

As well as potentially contributing directly to accident causation, higher-level decision-making has a major impact on an organization's safety climate (discussed in Chapter 8), by demonstrating the priority that safety is given in relation to other organizational goals. Safety climate acts as a frame of reference throughout an organization, which affects employees' attitudes, perceptions, and behaviors (Zohar, 1980).

9.1 *Trait and behavioral leadership theories*

Early leadership models included: the "great man" theory, which held that leaders were "born not made"; trait approaches, which focused on identifying supposed personality characteristics associated with effective leaders; leadership style approaches (e.g., the Ohio and Michigan State studies in the 1960s), which focused on defining leadership behaviors; and contingency approaches (e.g., Fiedler, 1967; Hersey & Blanchard, 1982; House & Mitchell, 1974; Vroom & Yetton, 1973), which considered interactions between leader characteristics and situational factors. "New leadership" theories followed, including charismatic leadership (House, 1977), and the influential transformational–transactional leadership theory (Bass, 1985). Subsequent developments included ethical leadership (Brown & Treviño, 2006; Brown, Treviño, & Harrison, 2005), authentic leadership (Avolio & Gardner, 2005), and empowering leadership (Arnold, Arad, Rhoades, Drasgow, & Wiley, 2000).

9.1.1 Trait theories

Early reviews of the leadership personality literature identified a number of personality traits that supposedly differentiated leaders from nonleaders. Stogdill (1974) concluded that factors frequently linked with leadership were activity, dominance, self-confidence, achievement drive, and interpersonal skills. A meta-analysis by Lord, De Vader, and Alliger (1986) found that compared with nonleaders, leaders tended to be more intelligent, extravert, dominant, masculine, conservative, and well adjusted. Kirkpatrick and Locke (1991) suggested that the traits that leaders possessed when compared with nonleaders were: intelligence, desire to lead, energy and ambition, self-confidence, honesty, and integrity. However, while these characteristics seemed to be commonly possessed by leaders, trait theories lacked an explanatory mechanism for linking personality to leader effectiveness, as mere possession of these personality traits and attributes was insufficient to make someone a successful leader. The lack of consistency over time, and across settings (Barling et al., 2011) suggested a role for moderator variables. Trait theories largely fell into disfavor until a resurgence of interest in personality as a determinant of behavior (discussed in Chapter 7).

One meta-analysis (Judge, Bono, Ilies, & Gerhardt, 2002) concluded that personality (and reported valid, generalizable effect sizes ranging from 0.16 to 0.24 for the relationship between the Big Five personality dimensions and leadership effectiveness). These findings were supported by DeRue, Nahrgang, Wellman, and Humphrey's (2011) meta-analysis, which found extraversion and conscientiousness to be the traits that were most predictive of overall leader effectiveness. Although there is evidence for the importance of personality traits in relation to leadership, the issue remains that possession of the "right" traits does not necessarily make for an effective leader. While researchers have examined personality traits associated with workplace safety in terms of employee behaviors (see Chapter 7), less research has focused on leader traits and safety leadership.

9.1.2 Behavioral theories

The behavioral style approach distinguished between two distinct styles of leadership: one (consideration) emphasizing relationships and the other (initiating structure) emphasizing the task (Fleishman & Harris, 1962)—see Summary Text 9.2. While early behavioral theories suggested that the optimal leadership style incorporated high levels of both consideration and initiating structure, there is little support for such a proposition (Barling et al., 2011; DeRue et al., 2011).

In their meta-analysis, Judge, Piccolo, and Ilies (2004) examined the relative effectiveness of these two behavioral styles of leadership. Both had moderately strong associations with leadership outcomes (consideration—.48; initiating structure—.29). While consideration was more strongly associated with leader satisfaction and leader effectiveness, initiating structure was more strongly associated with leader, group, and organization performance. However, simply having a leadership style that incorporated both types of behavior consistently across situations did not define the most effective leader.

Some of the earliest work on leadership style and workplace safety focused on the role of "consideration" as a form of relationship-oriented leadership, including supervisory consideration (Fleishman, Harris, & Burtt, 1955), and managerial concern for subordinates' well-being (Dunbar, 1975). In relation to safety, leaders high in consideration would take an active interest in subordinates' physical and psychological well-being, and be receptive to suggestions and safety concerns. There is evidence that supportive leadership is

SUMMARY TEXT 9.2 Behavioral Leadership: Consideration and Initiating Structure

Consideration indicates friendship, mutual trust, respect, and warmth. A leader with a high score on this dimension is likely to be friendly and approachable, with good rapport and two-way communication with subordinates, who is willing to help with personal problems, and thereby adopts a participative and empowering approach to leadership.

Initiating structure indicates a concern with defining and organizing roles or relationships within an organization, establishing well-defined forms of organization, channels of communication and ways of getting jobs done, and trying out new ideas and practices. A high score on this dimension characterizes individuals who are active in directing group activities through planning, communicating information, scheduling, assigning group members to particular tasks, and expecting workers to meet particular standards of performance and deadlines.

associated with employees' health and well-being (Nyberg et al., 2009), as well as their safety-related behavior.

Guest, Peccei, and Thomas (1994) found that workgroups with better safety records had supervisors who demonstrated concern for their subordinates by making workers feel valued, keeping them well informed, and treating them fairly. Correspondingly, a lack of social support from supervisors has been associated with occupational injury occurrences (Hemingway & Smith, 1999; Iverson & Erwin, 1997; Nahrgang, Morgeson, & Hofmann, 2011; Sherry, 1991). As discussed in Chapter 6, lack of social support may be a source of strain (stressor) for employees, or may act as a moderator (buffer) in the stress–strain relationship (Schaubroeck & Fink, 1998). There is also evidence that social support (including supervisory support) indirectly affects injuries, mediated by safe behavior (Oliver, Cheyne, Tomás, & Cox, 2002). While Tomás, Meliá, and Oliver (1999) reported a significant positive relationship between workers' safe behavior and supervisory response, Thompson, Kirk–Brown, and Brown (1998) found a significant relationship between supervisor support for safety and safety compliance by workers. Using the job demands–job resources model as a theoretical framework for understanding the impact of organizational factors on safety outcomes, Narhgang et al.'s (2011) meta-analysis identified supportive leadership as having significant positive relationships with a range of safety-related outcomes, including employee engagement, satisfaction, and safety compliance.

There is substantial evidence that supportive leadership has positive effects on workplace safety (e.g., Mullen, 2005; Parker, Axtell, & Turner, 2001; Zohar, 2002a), suggesting that leaders who score highly in individualized consideration (i.e., who demonstrate concern for their employees' safety and well-being) are more likely to encourage employees to share safety concerns and take action to improve working conditions. The likely psychological mechanism for the effects of individualized consideration is through leaders' willingness to listen to safety concerns (Hofmann & Morgeson, 1999; Mullen, 2005), which is likely to encourage safety participation from employees, and should lead to reduced hazards in the workplace.

Finding that supportive supervision had a positive lagged effect on safe working, Parker et al. (2001) showed that having supportive, coaching-oriented team leaders resulted in safer working over an 18-month period. This study provided evidence that experiencing this style of leadership positively affected workers' future behavior. A coaching leadership style emerged as having a particularly strong relationship with work performance, emphasizing the importance to safety of this type of leadership. Another finding was that the influence of supportive supervisory style had a direct effect on safety, which was not mediated by organizational commitment (Parker et al., 2001).

However, Zohar (2002a) argued that supervisory response to safety is an interactive function of concern for the members' welfare and safety priorities assigned by the senior management, so that a supportive management style would have less effect in promoting worker safety where safety is given a low priority. Workers' safety behavior was strongly influenced by supervisory practices (e.g., discussing safety issues with subordinates), which are more likely when a supervisor is concerned for subordinates' welfare. Another possible mechanism is via effects on communication, whereby supervisors willingly discuss safety issues with their subordinates (Hofmann & Morgeson, 1999; Parker et al., 2001). Unsurprisingly, greater willingness to volunteer safety concerns has been associated with supervisors who are perceived to be supportive and receptive to their supervisees' concerns (Mullen, 2005).

Although empirical evidence links the relationship-oriented/consideration aspects of leadership with workplace safety, limited attention has been paid to the more task-oriented/initiating structure elements. Work focusing on the latter is addressed in Section 9.3.3.

9.1.3 Integrating trait and behavioral leadership theories

DeRue et al. (2011) argued that some leader traits (conscientiousness, emotional stability, openness) are related to leader effectiveness via task competence, while other traits (extraversion, agreeableness) link to leader effectiveness via interpersonal skills. Supporting this integrative model, DeRue et al.'s meta-analysis found that 58% of variance in leader effectiveness was predicted by leader traits and leader behaviors. Although both traits and behaviors were strong predictors of leader effectiveness, behaviors accounted for a higher proportion of the variance.

9.2 Charismatic leadership

The notion of charismatic leadership shifted attention away from behavioral leadership theories to higher level constructs, such as charisma and vision. House (1977) identified ideal form charismatic leadership qualities. Charismatic leaders, through the force of their personalities and interpersonal skills, can articulate an appealing vision linking present with future and are said to have an extraordinary effect on followers or subordinates, without resorting to any formal authority. Their great power and influence, and their projection of an attractive set of values and modes of behavior, make it easy for subordinates to identify with them and to internalize their values, as well as imbuing a high degree of trust and confidence in them. Charismatic leaders, endowed with determination, energy, self-confidence, and ability, are capable of making self-sacrifices. They depart from conventionality in the way in which they express courage and conviction about their vision; they inspire and excite their subordinates with the idea that together, with extra effort, great things can be accomplished, and they do not necessarily have to offer extrinsic rewards (Kirkpatrick & Locke, 1996; Shamir, House, & Arthur, 1993).

The charismatic leadership concept unites the influence of leader traits (high self-confidence, strong beliefs in own views, need for power), leader behaviors (setting an example, high expectations, motivating, impression management), and conditions (stress, crisis point). Conger and Kanungo (1987) adapted this approach to reflect the idea that charismatic leadership involves a process whereby charisma is attributed to a leader where certain behaviors (e.g., vision, self-confidence, emotional appeal) are observed by followers. While charismatic leadership has not featured greatly in the safety literature, the importance of enthusing and inspiring employees to engage with a company's safety agenda has been addressed in relation to a transformational leadership (Section 9.3.1).

9.3 Transformational and transactional leadership

Leadership theories that sufficed as explanatory frameworks in the 1960s and 1970s were abandoned in favor of "New Leadership" theory, a concept more in tune with leadership practice in the more turbulent business environment of the 1980s. The best-known theory of this type is transformational leadership (Bass, 1985). In this process, leaders and followers transform each other to achieve high levels of effort and performance. Transformational leadership has four components: individualized consideration, intellectual stimulation, inspirational motivation, and idealized influence (see Summary Text 9.3).

Traditional transactional leadership approaches were often based on exchanging rewards (e.g., pay, status) for work effort or performance. Four aspects of transactional leadership described by Bass (1985) were: contingent reward, management-by-exception

---

SUMMARY TEXT 9.3 Elements of Transformational and Transactional Leadership

TRANSFORMATIONAL LEADERSHIP

- *Individualized consideration*: Leader shows interest in subordinates' personal and professional development, acts as mentor or coach, and listens to followers' needs and concerns.
- *Intellectual stimulation*: Leader challenges assumptions, takes risks, solicits followers' ideas, and stimulates and encourages subordinates to be creative and innovative.
- *Inspirational motivation*: Leader inspires others toward goals and provides meaning, optimism, and enthusiasm; articulates a vision that is appealing and inspiring to others.
- *Idealized influence*: Leader inspires confidence and is perceived as charismatic; behaves in admirable ways that cause the followers to identify with the leader.

TRANSACTIONAL LEADERSHIP

- *Contingent reward*: Leader exchanges reward for effort or performance.
- *Management by exception—active* (MBEA): Leader anticipates problems and takes corrective action by actively monitoring followers' behavior.
- *Management by exception—passive* (MBEP): Leader spots and corrects followers' mistakes as problems arise.
- *Laissez-faire*: Leader is not involved in the followers' work, but is absent, disorganized, or indifferent.

---

active (MBEA), management-by-exception passive (MBEP), and laissez-faire (see Summary Text 9.3). It has been argued that laissez-faire actually represents a form of nonleadership and should therefore be classed as neither transformational nor transactional leadership (Avolio, 1999; Bass, 1998). DeRue et al. (2011) argued that there was overlap between transformational leadership and consideration (elements of individualized consideration and idealized influence) and also between initiating structure and transactional leadership.

Transformational leadership has been one of the most active research areas over the past 30 years, generating numerous studies. For example, across a variety of organizational settings (military, industrial, health care, and voluntary sectors), Bass (1997, 1998) provided much empirical support for transformational leadership effectiveness across a range of organizational and individual outcomes, including productivity, job satisfaction, and commitment. Meta-analyses have provided strong support for the effectiveness of transformational leadership (DeRue et al., 2011; Judge & Piccolo, 2004; Lowe, Kroeck, & Sivasubramaniam, 1996). Judge and Piccolo (2004) found that contingent reward was almost as effective as transformational leadership, particularly in business organizations, and that to a lesser extent MBEA was also a significant predictor of leader effectiveness. Parry (2002) found that a better psychometric fit for leadership data was between transformational and separate active and passive management categories, with laissez-faire as one component of passive management. Laissez-faire leadership has emerged as highly undesirable, with MBEP also producing significant negative results against all criteria (Judge & Piccolo, 2004).

Yukl (1998) suggested that transformational leadership achieved its effect through two processes, whereby followers identified with the leader (personal identification), and with the workgroup (social identification). High performance in followers was achieved through increased ability and motivation. Empowering behaviors, such as delegating responsibility, aid performance by encouraging followers to think for themselves and to become more creative (Dvir, Eden, Avolio, & Shamir, 2002). Kark, Shamir, and Chen (2003) argued that the positive effects of transformational leadership (e.g., enhanced self-efficacy, collective efficacy, and organization-based self-esteem, which are all indicators of empowerment) result from social identification with the workgroup, whilst negative effects (e.g., follower dependence on the leader) are mediated by personal identification with the leader. Where personal identification is the primary mechanism through which a transformational leader exerts influence, this may allow leaders to promote dependence without empowerment, with potentially negative effects for employees.

Bass and Steidlmeier (1999) suggested that the ethics of leadership depended upon the leader's moral character, the ethical legitimacy of values embedded in the leader's vision, and the morality of the processes of social ethical choice and action that leaders and followers engaged in, and collectively pursued. Howell and Avolio (1992) argued that only *socialized* leaders, concerned for the common good, could truly be transformational leaders; while *personalized* leaders, who were primarily concerned with their own self-interests, could not truly be transformational leaders.

Criticism of the model (Van Knippenberg & Sitkin, 2013) highlighted the lack of conceptual clarity, given that there is a high level of overlap between transformational leadership and other leader concepts, such as consideration (e.g., DeRue et al., 2011, found a correlation of .71), as well as difficulties in defining transformational leadership in terms of its effects. There is also a lack of distinction between the different components of transformational leadership, both conceptually and empirically. For example, the components are usually assumed to be additive, which is supported by empirical findings that all components are closely correlated. This leads to some disconnect between the (unidimensional) measurement model and the (multidimensional) conceptual model. Furthermore, Van Knippenberg and Sitkin (2013) discussed the under-development of the causal model of transformational leadership, which provides little theoretical guidance in terms of mediators and moderators of the relationship with leader effectiveness.

9.3.1 Transformational leadership and safety

Research has mostly emphasized the positive influence of transformational leadership on employees' safety perceptions, attitudes, and behavior (e.g., Barling, Loughlin, & Kelloway, 2002; Conchie & Donald, 2009; Kelloway, Mullen, & Francis, 2006; Zohar & Luria, 2004). Evidence has demonstrated that transformational leadership is associated with a number of safety outcomes, including injury rates (Barling, Loughlin, & Kelloway, 2000; Barling et al., 2002; Yule, 2002; Zohar, 2002b), and safety-related behavior (Conchie & Donald, 2009; Inness, Turner, Barling, & Stride, 2010). Transformational leadership generates a better understanding of safety issues and improved communication (Conchie, Taylor, & Donald, 2012), and builds consensus among employees' perceptions of the priority given to safety (Luria, 2008; Zohar & Tenne-Gazit, 2008). Studying group interactions within military platoons using social network analysis, Zohar and Tenne-Gazit (2008) showed that communication density (extent of platoon members' interactions) mediated the effect of transformational platoon leaders on the subsequent development of group safety climate. This study thereby demonstrated an effect of transformational leadership at group level, whereby leaders encouraged platoon members to develop shared perceptions of safety (group safety climate) through promoting shared values, setting collective goals, and teamwork.

While the four components of transformational leadership are defined as distinct leader behaviors, in practice they tend to intercorrelate closely to the extent that transformational leadership is often treated as being unidimensional. This has been the case with most research within health and safety. However, a number of different psychological mechanisms could potentially underpin the relationships between different leader behaviors and their effects on employees' perceptions, attitudes, and behavior.

Intellectual stimulation reflects a leader's ability to challenge existing assumptions and encourage employees to think creatively and to be innovative. Rafferty and Griffin (2004) defined intellectual stimulation as, ". . . enhancing employees' interest in, and awareness of problems, and increasing their ability to think about problems in new ways" (p. 333). Barling et al. (2002) suggested that this leadership style encouraged employees to address safety issues and to share information concerning safety risks. Intellectual stimulation may help to counter some dysfunctional aspects of groups; for example, teams that develop strongly held norms concerning safety could develop highly routinized behavior that is subjected to little scrutiny. Having a team leader whose leadership style is characterized by intellectual stimulation could help team members to question their assumptions and challenge them to develop novel solutions to safety problems. This could enhance the team's capacity for long-term learning and their performance in terms of safety (and other performance criteria).

Effective learning from injuries is enhanced within teams characterized by open communications (Hofmann & Stetzer, 1998). This leadership style may aid learning by stimulating team members to critically examine performance shortcomings that could lead to injuries. Intellectual stimulation may also facilitate effective group decision-making processes by encouraging team members to examine all possibilities, actively seek contrary evidence, and solicit expert opinion. However, it is also possible that this aspect of transformational leadership could have adverse effects on safety, as intellectual stimulation might encourage risk-taking, given that employees are encouraged to seek novel and creative ways of working (Clarke, 2013). While empirical evidence is mixed regarding the influence of intellectual stimulation on safety, no studies have reported negative effects. For example, while Yule (2002) found that leaders perceived to be intellectually stimulating tended to lead the safest business units (with low injury rates), Hoffmeister et al. (2014) found no relationship between intellectual stimulation and occupational injuries.

While there is evidence that individualized consideration is associated with lower rates of occupational injuries (Yule, 2002), idealized influence affects employee performance through identification with the superior as role model and moral leader. Barling et al. (2002) argued that leaders influenced their employees to perceive safety as a social responsibility by expressing their personal commitment to maintaining safety. Rather than compromising safety to meet production demands, identification with the leader encourages subordinates to prioritize safety goals as being the right thing to do. This aspect of transformational leadership may be important in shaping safety climate by strengthening subordinates' perceptions of management commitment to safety.

Where leaders continue to demonstrate idealized influence in relation to their personal commitment to safety standards, this should help to maintain positive team safety climate. It is also likely to aid development of appropriate group norms that embody safety as the top priority. Where team members identify with the leader, his/her personal commitment to safety will translate into group norms that are accepted within the team. Hoffmeister et al. (2014) found that idealized influence was the most important aspect of transformational leadership, as idealized attributes and idealized behaviors consistently emerged as the most important predictors of safety at work. Idealized attributes were the most important for establishing a positive safety climate, whereas idealized behaviors were most important for safety participation.

A leader employing inspirational motivation articulates the organizational vision and inspires subordinates toward organizational goals through his or her optimism and enthusiasm. In relation to safety, Barling et al. (2002) suggested that inspirational motivation has a positive effect by challenging team members to go beyond individual needs for the collective good—for example, engaging in organizational citizenship behaviors (OCBs) and safety-related activities, by convincing their followers that high levels of safety are attainable. Indeed, Griffin and Hu (2013) found that leadership characterized as "safety inspiring" (e.g., leader "inspires team members to support safety at work," and "presents a positive vision of safety for the team") was significantly associated with employees' safety participation. Investigating the effects of leader influence tactics on safety participation, Clarke and Ward (2006) found that "inspirational appeals" (similar to inspirational motivation) were associated with higher levels of employees' safety participation. However, there is little evidence that such leader behaviors have a direct association with occupational injuries (Hoffmeister et al., 2014; Yule, 2002).

9.3.2 Contingent reward

Although not a dimension of transformational leadership, contingent reward is often considered alongside the four transformational components as it correlates strongly with these components, and is positively associated with performance outcomes (Judge & Piccolo, 2004). However, evidence relating to this style of leadership is mixed.

While contingent reward has been associated with reduced minor injury rates in a relationship fully mediated by safety climate (Zohar, 2002b), it has also been linked with higher, rather than lower, injury rates (Yule, 2002). Hoffmeister et al. (2014) found that when considered alongside other aspects of leadership, contingent reward was not associated with safety outcomes.

Judge and Piccolo's (2004) meta-analysis showed that although transformational leadership was associated with follower satisfaction and motivation, contingent reward had stronger relationships with performance criteria. However, while transformational leadership generalized across settings, context affected contingent reward leadership, such that its effect was much stronger in business settings. Judge and Piccolo (2004) suggested that this finding related to resource availability, in that business leaders typically had greater access to tangible resources to reward professionals for their efforts. Where leaders had access to fewer resources, they may be less able to fulfill their part of the exchange, making contingent reward leadership less effective in these circumstances. As much safety research has focused upon industries where a high level of tangible resources would not be expected (e.g., public sector, manufacturing, construction, transport, offshore oil, and gas), this might account for negative relationships found between contingent reward and injuries. This would suggest that a contingent reward leadership style would be less effective in promoting safety, compared with other performance criteria.

As safety goals may conflict with other performance (e.g., production-related) outcomes, rewards associated with production—for example, performance bonuses, may override rewards associated with safe performance, as leaders prioritize production goals above safety goals, thereby making some outcomes more desirable than others. Supporting this position, Zohar (2002b) demonstrated that contingent reward effectively promoted a positive safety climate only when safety was assigned as a high priority (but not when it was assigned as a low priority), as only then did supervisors view safety as a legitimate performance goal.

9.3.3 *Transactional leadership and safety*

Findings on other transactional leadership forms described by Bass (1985) have varied from small positive effects for active transactional leadership (MBEA) to substantial negative effects for passive leadership (MBEP, laissez-faire) on leader effectiveness and performance (Judge & Piccolo, 2004). These findings indicated that only MBEA, where leaders monitor employees' behavior, anticipate problems, and take corrective actions, is likely to be positively associated with safety performance.

Relatively little research has considered effects of transactional leadership on safety performance. By influencing employee safety participation and perceptions of safety climate, Clarke and Ward (2006) showed that both transformational and transactional leader behaviors could have beneficial effects on safety. Leadership influence tactics identified as significant predictors of workplace safety were rational persuasion, inspirational appeals, and consultation. Rational persuasion, which is associated with transactional leadership style, emerged as the most powerful leader influence tactic of safety behavior. Coalition (another leader influence tactic related to transactional leadership) also showed a direct positive effect on safety behavior. This study therefore suggested that transactional leader behaviors could be as effective as transformational behaviors in enhancing employee safety performance. Indeed, Clarke and Ward (2006) demonstrated that rather than exclusively using one form of behavior, a combination of transformational and transactional tactics might be most effective for influencing employee safety behaviors. For example, a leader may provide an initial rationale for following safety rules and regulations through active monitoring of safety performance and offering incentives for safety compliance (transactional leadership), and then further promote safety through inspirational appeals and intellectual stimulation (transformational leadership). Within a contingency framework (see Section 9.5), a leader would need to determine which tactics were most appropriate in different situations (Clarke, Guediri, & O'Connor, 2013).

Although relatively little research has considered the effects of active transactional leadership in relation to safety performance, drawing on the organizational safety and high-reliability organization (HRO) literature, Clarke (2013) argued that active transactional leadership should have a positive influence on workplace safety. This would be particularly evident in safety-critical organizations where major incidents may be prevented through proactive monitoring and error correction. Active transactional leaders (based on MBEA) monitor employees' behavior, anticipate problems, and take proactive steps to implement corrective actions, thereby providing opportunities for error recovery and learning from mistakes, which are key elements of a "learning culture" (Reason, 1997). This is similar to the "preoccupation with failure" (Weick & Sutcliffe, 2001) that is characteristic of HROs operating within high-risk environments, but with exemplary safety performance (Clarke, 2013). Given that such organizations have requirements for compliance, reliability and integrity to ensure safety, employees must be aware of the risks, but also be compliant with rules and regulations, in order to meet the need for concurrent standardization and flexibility required in HROs (Grote, Weichbrodt, Gunter, Zala-Mezo, & Kunzle, 2009).

Safety-critical organizations, with a requirement for reliability and compliance, are suited to active transactional leadership behaviors (Rodriguez & Griffin, 2009). Leaders within such organizations learn to anticipate potential adverse events by continuously monitoring employees' behavior, and so are better prepared to intervene to prevent incident occurrences (Griffin & Hu, 2013; Rodriguez & Griffin, 2009). Thus, engaging in active transactional leadership can enable leaders to learn how to anticipate and prevent safety incidents and adverse events. Such leader behavior should also promote close attention to safety rules and regulations by employees, leading to greater safety compliance and enhanced perceptions of the importance of safety (Clarke, 2013).

In a meta-analysis of safety leadership studies, Clarke (2013) found support for a model in which transformational leadership was directly related to safety participation, and active transactional leadership was directly related to safety compliance. Similar findings were reported by Griffin and Hu (2013), who examined leadership as "safety inspiring" and "safety monitoring." Safety-inspiring leader behaviors (similar to transformational aspect of inspirational motivation) were directly related to safety participation; safety-monitoring leader behaviors (e.g., leader "scans the environment for unsafe actions by the team," and "lets me know if I am working unsafely"), which align with active transactional leadership, were directly related to safety compliance. Griffin and Hu's (2013) study was based on a sample of working adults from a broad range of occupations and work roles, thereby demonstrating the generalizability of findings outside high-risk work environments.

9.3.4 Passive leadership and safety

Passive leadership has generally been found to be an ineffective approach (Judge & Piccolo, 2004), and would be expected to have a strong negative association with safety performance. Leaders who intervene to deal with safety issues only when they become serious enough to warrant their attention (MBEP) or take no responsibility in ensuring workplace safety (laissez-faire) are likely to have little influence in reducing workplace hazards or preventing safety incidents. Indeed, Kelloway et al. (2006) found that passive leadership had significant negative effects on safety, leading to increased incidence of occupational injuries and adverse safety events. Passive leadership also reduced the level of safety consciousness and perceptions of the importance of safety (safety climate). Exploring the influence of passive leadership on the development of group safety climate, Luria (2008) revealed that passive leaders disrupted the formation of shared views regarding the importance of safety (i.e., reduced climate strength).

Further to the negative effects of passive leadership, Mullen, Kelloway, and Teed (2011) explored the potential effects of "inconsistent leadership," whereby leaders tended to alternate between transformational and passive leadership styles, or demonstrated behaviors associated with both styles. The study supported Kelloway et al.'s (2006) findings that passive leadership reduced workplace safety. These authors also reported that passive leader behavior (e.g., avoiding safety issues) attenuated the positive effects of a transformational leadership style. Kelloway et al. (2006) also found that this effect was stronger for a sample of young health care workers compared with a sample of older workers. Thus, the safety-related behavior of young employees was particularly susceptible to the occasional passive response to safety by their supervisors and managers.

In addition to research findings, a number of prominent disasters have illustrated the effects of poor management. For example, the public enquiry report on the 1988 *Piper Alpha* disaster (Cullen, 1990), which claimed 167 lives, criticized the performance of the offshore installation managers (OIMs) at the time of the disaster. The report noted that offshore oil companies could do more to enable the OIMs to act proactively in crises (see also Summary Text 9.1).

9.4 Other leadership models

Other leadership theories that have been explored in relation to safety include empowering leadership (Arnold et al., 2000), ethical leadership (Brown & Treviño, 2006; Brown et al., 2005), and authentic leadership (Avolio & Gardner, 2005). Although research has demonstrated that other leadership models are associated with safety outcomes, it was not always clear whether these theories added value over and above the effects of transformational–transactional leadership.

9.4.1 Empowering leadership

The empowering leadership model (Arnold et al., 2000) concerns leadership at team level, where the leader's main function is to facilitate self-management within a team. The model has five categories of leader behavior: leading by example (acting as a role model), participative decision making (encouraging involvement, employees voicing their ideas and suggestions), coaching (encouraging self-management, sharing of knowledge), informing (effective communication of information from the leader), and showing concern/interacting with employees (demonstrating concern for employees' well-being). Several of these dimensions overlap with aspects of transformational leadership, including leading by example (idealized influence), participative decision making (intellectual stimulation), and showing concern/interacting with employees (individualized consideration).

Within nuclear power plants, Martínez-Córcoles, Gracia, Tomás, and Peiró (2011) found that empowering leadership was associated with perceived safety climate and safety behavior, with safety climate mediating the effects of leadership on employee behavior. Empowering leadership affected safety behavior by creating a collaborative learning environment (Martínez-Córcoles, Schöbel, Gracia, Tomás, & Peiró, 2012). Using multilevel modeling, Martínez-Córcoles, Gracia, Tomás, Peiró, and Schöbel (2013) also showed that empowering leadership (at team level) influenced individual-level safety behavior (enhanced safety compliance and safety participation, and reduced risky behaviors).

9.4.2 Ethical leadership

Ethical leadership is concerned with exemplifying ethical behavior, treating people fairly, and actively managing morality (Mayer, Aquino, Greenbaum, & Kuenzi, 2012). Research has demonstrated that this style of leadership is associated with increased OCBs, employees speaking up about their concerns (voice), and enhanced psychological safety (Piccolo, Greenbaum, den Hartog, & Folger, 2010; Walumbwa & Schaubroeck, 2009). There is some overlap between the construct of ethical leadership and the transformational leadership dimension of "idealized influence." For example, Ogunfowora (2014) demonstrated that the positive effects of ethical leadership on unit-level OCBs and individual-level job satisfaction were accentuated when leader role-modeling strength was high. Thus, ethical leaders who acted as ethical role models were particularly likely to facilitate employee OCBs.

These positive effects are likely to extend to safety behavior. For example, Credo, Armenakis, Feild, and Young (2010) found that perceived organizational ethics and perceived organizational support provided an important context for senior management messages reinforcing workplace safety. While few studies have specifically measured ethical leadership in relation to safety, Chughtai (2015) found that ethical leadership was associated with enhanced safety performance (compliance and participation) in a sample of Pakistani doctors.

9.4.3 Authentic leadership

Another form of positive leadership, authentic leaders are defined as being true to their core beliefs and values and exhibiting authentic behavior, while positively fostering the same authenticity in their followers (Avolio & Gardner, 2005; Luthans & Avolio, 2003), within the context of a supportive organizational climate (Gardner, Avolio, Luthans, May, & Walumbwa, 2005). There is conceptual overlap with ethical leadership as authentic leaders display a moral perspective and lead by example. The authentic leadership construct also draws on the transformational–transactional leadership model (Gardner et al., 2005).

Positive forms of leadership would be expected to have beneficial effects on employees' attitudes and behavior in relation to safety. For example, Yan, Bligh, and Kohles (2014) found that positive forms of leadership (particularly authentic and transformational) fostered an environment in which employees were able to learn from errors. Leaders high in authentic leadership contributed to the development of a positive safety climate (Borgersen, Hystad, Larsson, & Eid, 2014), which in turn affected employees' perceptions, attitudes, and behavior, including risk perceptions (Nielsen, Eid, Mearns, & Larsson, 2013). The effects of authentic leadership are proposed as mediated by psychological capital (Eid, Mearns, Larsson, Laberg, & Johnsen, 2012), which has been defined as ". . . one's positive appraisal of circumstances and probability for success based on motivated effort and perseverance" (Luthans, Avolio, Avey, & Norman, 2007, p. 550). Thus, positive forms of leadership lead to positive safety outcomes for employees.

9.5 Contingency theories

Contingency theories consider leadership within an organizational context. Although a number of well-known theories are described here, several are no longer used and are rarely cited in contemporary research. Nevertheless, understanding the leadership context is still recognized as an important consideration, as the effectiveness of leader behaviors varies between work environments (Antonakis, Avolio, & Sivasubramaniam, 2003; Liden & Antonakis, 2009; Rowold, 2011; Schriesheim, Wu, & Scandura, 2009).

Hersey and Blanchard (1982) extended the relationship/task dimensions of leadership to four styles (tell, sell, participation, delegation), which must be matched to subordinates' maturity. Maturity is considered in the context of a particular task and consists of: (1) job maturity (relating to technical knowledge and task-relevant skills), and (2) psychological maturity (relating to feelings of self-confidence and ability, and people's willingness to take responsibility for directing their own behavior). While the theory has not undergone significant evaluation to test its validity, it is widely used in training programs. Vecchio (1987) concluded that the model's predictions were most accurate for low-maturity subordinates, but not very accurate for high-maturity subordinates.

Fiedler (1967) attempted to predict how leadership style, leader–member relations, power vested in the leader position, and job or task structure, harmonized to determine a leader's ability to achieve productive output. While Fiedler's contingency theory of leadership has been criticized (Graen, Orris, & Alvares, 1971), other evidence supports substantial parts of the theory (Schriesheim, Tepper, & Tetrault, 1994).

Vroom and Yetton (1973) outlined different styles of decision making or leadership (e.g., autocratic, consultative) to cope with both individual and group problems from which a leader chooses the most appropriate form for the situation. The model may have greater applicability for leaders than for subordinates. For example, in Field and House's (1990) study, subordinates disliked the autocratic style even in circumstances where the model indicated this style to be the most appropriate. Another factor to consider is the skill of the leader in putting their chosen decision style into practice (Tjosvold, Wedley, & Field, 1986), as even the theoretically correct style may be unsuccessful if handled with poor skills.

Path-goal theory (House & Mitchell, 1974) suggested that a leader is more effective if s/he can help subordinates strive toward their goals. The theory is concerned with explaining the relationship between a leader's behavior and subordinates' attitudes and expectations. Evidence suggests that a path-goal leader, who can compensate for weaknesses in subordinates or in work situations, is likely to have a beneficial effect on worker satisfaction and performance, provided that competent subordinates are not oversupervised (Keller, 1989). While evidence is generally supportive, there is a call for the theory to be refined by adding further moderating variables (Evans, 1996; Schriesheim & Neider, 1996; Wofford & Liska, 1993).

Situations may arise in which there are sufficient factors independent of leadership that support subordinates to the extent that they do not have to rely on a leader for guidance—for example, ability, training, and previous experience (Kerr & Jermier, 1978; Podsakoff, MacKenzie, & Bommer, 1996). These factors could deliver effective performance even with an unsatisfactory group leader. In effect, competent subordinates often require little supervision. Kerr and Jermier (1978) suggested that effective group performance depended on factors other than leadership and therefore leadership should be recognized as merely another independent variable among many that influence worker satisfaction and performance; support for this position being obtained from Williams et al. (1988) and Yukl (1998).

Leadership substitutes include subordinates' abilities and skills, as well as intrinsically satisfying tasks, explicit formalized goals, rigid rules and procedures, cohesive groups, and knowledgeable officials, other than the leader, whom subordinates can consult. For example, where a task is interesting or satisfying, subordinates may be motivated by the work itself, thereby negating the need for direct supervision. Where tasks are simple or repetitive, or feedback on progress is available, it may be unnecessary for leaders to provide advice or feedback. Likewise, little direction is needed from a leader when goals/objectives, and rules/procedures are clearly stated and accepted. With regard to group cohesiveness, a workgroup comprising a close-knit team of competent individuals capable of taking initiatives without direction (e.g., an emergency services team) creates less need for intervention by a leader. In contrast, a *leadership neutralizer* stops a leader from taking action in some way. For example, the leader's position may not be endowed with sufficient power, or the leader does not have adequate organizational rewards to dispense, or there may be physical distance between leader and subordinates. Vecchio (2003) noted that leadership substitutes theory helps to explain mixed results, as many leadership studies have failed to recognize the effect of neutralizers and substitutes, and so may produce nonsignificant results.

Although leadership substitutes theory has intuitive appeal, relatively little published evidence has supported it (Dionne, Yammarino, Atwater, & James, 2002). This may be partly due to the difficulty of identifying moderator variables (Villa, Howell, Dorfman, & Daniel, 2003), although some studies have identified such moderators, encouraging a renewed interest in leadership substitutes theory. For example, Rowold (2011) examined the moderating effect of team heterogeneity (in terms of gender, age, and culture) on the relationship between leadership style and team performance. The study found that team heterogeneity moderated the effects on performance of both transformational leadership and consideration (Rowold, 2011). Transformational leaders and leaders in high consideration had a particularly powerful effect on team performance in gender-balanced teams. Den Hartog and Belschak (2012) argued that moderating effects may also have been obscured in earlier research as substituting effects may be contingent. These authors supported a contingency model in which employees' job autonomy affected whether their self-efficacy was a substitute for transformational leadership behavior. Thus, the effect of transformational leadership on proactive behavior was moderated by both individual (self-efficacy) characteristics and by situational (job autonomy) factors (Den Hartog & Belschak, 2012).

9.6 Psychological mechanisms linking leadership to safety outcomes

Previous discussion has established the importance of leaders and leader behavior as an antecedent of employees' attitudes, perceptions, and behavior. Other research has considered underlying psychological mechanisms linking leadership to safety outcomes, including safety climate and trust processes. Researchers have also examined moderating effects, which have provided information about relationship boundary conditions, for example, the context within which leadership affects safety performance.

9.6.1 Interpersonal trust and leader integrity

Trust is worthy of study in organizational behavior (e.g., Whitener, 1997), particularly in relation to workplace safety (e.g., Conchie & Donald, 2009). Trust underlies many interpersonal relationships, including those with spouses, coworkers, and bosses. As we experience another's behavior, we may develop confidence over time that we can rely on that other person. In any situation where trust enters the frame, risk and vulnerability are inevitable and there is always the prospect that we could be disappointed or taken advantage of when we freely give important information or promises to another person. Schindler and Thomas (1993) identified these key characteristics of trust:

- *Integrity*—Honesty and truthfulness, probably the most important, going to the core of character
- *Competence*—People's technical knowledge and interpersonal skills to deliver what they maintained they were capable of doing
- *Consistency*—Predictable performance and sound judgment in handling situations
- *Loyalty*—When someone is confident that another person will not act to your disadvantage when pursuing a particular line of action, instead they will act in a loyal way
- *Openness*—When someone is transparent in their actions

In the trait approach to leadership (see Section 9.1.1), personality characteristics, such as honesty and integrity, which reflect the trustworthiness of the leader, have been associated with effective leadership. Colquitt, Scott, and LePine's (2007) meta-analysis revealed that integrity was strongly related to trust (effect size 0.62), and was particularly important for trust in the leader (compared to trust in others, such as coworkers). In relation to workplace safety, Conchie, Taylor, and Charlton (2011) found that honesty was ranked as the most important factor by employees in the development of trust (or distrust) in their supervisors' leadership. Trust is an important prerequisite of leading others, as it is very difficult to exercise leadership if subordinates do not trust their leader. On the other hand, trust will exist if subordinates can safely place themselves in the hands of the leader in the belief that s/he will act in their best interests. Applying techniques such as business process reengineering and downsizing by management have been shown to affect trust in management adversely (Robinson, 1996).

Trust in managers has been associated with better organizational performance. For example, Davis, Schoorman, Mayer, and Tan (2000) found a significant positive relationship between employee trust in general managers of restaurants and the performance of their business. In addition, general managers who were perceived as trustworthy were also perceived to be higher in ability, benevolence, and integrity. The key to developing trust in managers is effective communication with workers and competent decision making (Whitener, 1997). Although much research has focused upon supervisor–subordinate relationships, Whitener (1997) argued that trust at this level could generalize into a deeper and organization-wide sense of trust and respect. Perceptions of leadership style and effectiveness of HR practices have predicted workers' trust in division heads (McCauley & Kuhnert, 1992), while these variables also predicted workers' trust in their CEO and top management (Costigan, Insinga, Kranas, Kureshov, & Ilter, 2004). Thus, the relationship between first-line managers and employees is likely to be important for fostering trust in senior management.

Trust in management underpins employees' perceptions of managerial commitment to safety and their ability to protect workers' health and well-being. Watson, Scott, Bishop, and Turnbeaugh (2005) found that steel industry workers' trust in their supervisor was significantly related to their perceptions of work environment safety. Some evidence suggests that trust in management acts as a mediating variable in the relationship between organizational work practices and safety outcomes. Thus, positive organizational work practices increased workers' trust in their managers, which influenced safety incidents, including near-misses and minor injuries (Zacharatos, Barling, & Iverson, 2005). Trust has emerged as a key aspect of transformational leadership (see Section 9.3.1) as the relationship with the leader is characterized by a high degree of trust and confidence (Jung & Avolio, 2000). There is also evidence that trust in management mediates the effect of transformational leadership on performance (Jung & Avolio, 2000; Pillai, Schriesheim, & Williams, 1999).

Examining the effects of safety-specific transformational leadership style in leader–subordinate dyads on safety behavior (safety voice) in the oil industry, Conchie et al. (2012) found that the relationship was mediated by affective trust in leader, such that transformational leader behaviors helped to build affective trust in the leader, which in turn increased employee willingness to voice safety concerns. Examining soldiers' perceptions of trust in their leaders, perceived safety climate and injury rates, Luria (2010) found that trust was negatively related to injuries and positively related to safety climate. Trust was also related to the strength of safety climate within platoons, suggesting that trust in the leader facilitated shared perceptions of the importance of safety. Furthermore, safety-climate level mediated the relationship between trust and injury rates, such that trust developed a positive safety climate, which in turn affected injury likelihood.

Other work on the leader–subordinate relationship and safety has identified trust as a potential moderator. For example, Conchie and Donald (2009) showed that the extent to which employees trusted their leaders with regard to safety affected the strength of the effect of leadership on safety such that, when the leader was highly trusted, the effect of leadership on safety was strengthened (leading to enhanced safety behavior), but when the leader was less trusted, the leader's behavior had a weaker effect on safety behavior. These findings suggested that employees were more likely to view a trusted leader's behavior in a positive light and respond favorably, whereas a less-trusted leader may perform the same behaviors, but generate a much less favorable response (Dirks & Ferrin, 2002). In practice, therefore, trusted leaders were perceived as more knowledgeable and competent in relation to safety, and their safety communications were more likely to be accepted and acted upon.

Conchie (2013) developed a moderated-mediation model, whereby the mediating effect of intrinsic motivation in the relationship between transformational leadership and safety behaviors (whistle-blowing and safety voice) was moderated by trust in the leader. When employees had a high level of trust in the leader, intrinsic motivation mediated the effects of transformational leadership on safety citizenship behaviors (whistle-blowing and voice), but was unrelated to helping behavior. The study demonstrated that trust in leaders was particularly important if employees were expected to speak up about safety concerns and to challenge those who did not behave safely (Conchie, 2013). While studies have focused on the influence that leaders have on their employees' attitudes, perceptions, and behavior, it should also be noted that trusted leaders will have higher levels of safety commitment, as they are concerned with their employees' safety and well-being, meaning that leaders have an increased focus on improving workplace safety (e.g., minimizing hazardous working conditions and making safety training available).

While a lack of integrity is linked to distrust in safety leadership (Conchie et al., 2011), integrity and ability have been identified as the most important managerial characteristics for developing employees' trust in leadership (Colquitt et al., 2007). To build trusting relationships with employees, Robbins, Millett, Cacioppe, and Waters-Marsh (2001) suggested that a leader should subscribe to these principles:

- Keep people informed about various aspects of their work and their significance within the broader context of corporate activities
- Be objective and fair in your dealings with people

- Build capacity to share your feelings with others
- Since integrity is crucial for trust, tell the truth; be consistent in your behavior as mistrust could arise from inconsistency or not knowing what to expect
- Foster dependability by keeping to your word and promises; maintain confidences because divulging them could be viewed as untrustworthy
- Project confidence in the way you exercise technical and interpersonal skills

Consistency between a leader's words and actions is critical to ensuring safety (Zohar, 2000). This alignment between words and deeds has been examined as the concept of "behavioral integrity" in relation to safety (Halbesleben et al., 2013; Leroy et al., 2012). In a longitudinal study of registered nurses based in the United States, acute-care hospitals, Halbesleben et al. (2013) found that behavioral integrity predicted subsequent safety behavior (safety compliance) and psychological safety toward the leader, which in turn predicted safety outcomes. At team level, behavioral integrity predicted subsequent reporting of treatment errors (Leroy et al., 2012), demonstrating that behavioral integrity is important not only for occupational safety, but also for patient safety.

9.6.2 Leader–member exchange theory

Leader–member exchange (LMX) theory, also known as *vertical dyad linkage theory*, emphasizes subordinate participation and influence in the decision-making process (Dansereau, Grean, & Haga, 1975). An important implication of LMX theory is that leadership can best be understood by focusing on dyads (pairs of relations) made up of leader and member (a vertical relationship) rather than concentrating on leadership style averaged across all members, which assumes that all subordinates are treated in the same way.

The LMX relationship between leader and member develops quickly and remains stable over time, with leaders drawing a distinction between subordinates who are members of either in-groups (characterized by high LMX relationships) or out-groups (low LMX relationships). Although it is not clear how subordinates are classified into these subgroups, evidence suggests that leaders consider subordinates to be in-group members where the latter have personal characteristics compatible with those of the leader, and are likely to be extravert with a higher level of competence, compared with out-group members (Duchon, Green, & Taber, 1986; Liden, Wayne, & Stilwell, 1993).

An in-group comprises workers who the leader believes are competent, trustworthy, motivated to work hard, and who can accept responsibility. Out-group members are thought not to possess these traits. Consequently, the leader feels confident to allocate responsibility for important tasks to in-group members, thereby making his or her job easier. In turn, the leader reciprocates by offering support, understanding, and a more personal relationship for in-group members. As the two parties interact over time, these exchanges build the relationship. Evidence indicates that in-group members have a higher level of performance and satisfaction than do out-group members (Phillips & Bedeian, 1994). In contrast, the leader is inclined not to bestow favors on out-group members. They are given tasks requiring less ability and responsibility and tend not to benefit from a personal relationship with the leader. In fact, a leader's interactions with out-group members are based on his or her formal authority, rather than respect or friendship. A low LMX relationship is one that exists within the bounds of the employment contract, such that a worker performs his or her job, but contributes nothing extra (Bauer & Green, 1996).

There is substantial support for the LMX theory of leadership (Graen & Uhl-Bien, 1995; Settoon, Bennett, & Liden, 1996). In a review of LMX research, Schriesheim, Castro, and

Cogliser (1999) argued that six dimensions predominate: mutual support, trust, liking, latitude, attention, and loyalty. While high LMX relationships have been associated with numerous benefits, such as improved performance and OCBs (Settoon et al., 1996), lack of high-quality exchange relationships have been associated with negative consequences (not just an absence of positive effects). For example, Townsend, Phillips, and Elkins (2000) showed that performance and citizenship were positively related to LMX, but that LMX was negatively correlated with retaliation behavior. A high LMX relationship is characterized by mutual trust, respect, and liking. This relationship not only impacts subordinates' behavior, but also that of the leader. Mayer, Davis, and Schoorman (1995) found that trusted leaders engaged in more "risk-taking behaviors" (such as delegation and empowerment), whilst their subordinates demonstrated more OCBs and enhanced performance.

Leader–member exchange relationships are based on social exchange. In low LMX relationships, subordinates will not feel obligated to go beyond the bounds of their employment contract (Bauer & Green, 1996), while in high LMX relationships subordinates repay the leader for a high-quality relationship by engaging in extra-role behaviors (Settoon et al., 1996). In organizations where safety is prioritized, subordinates may engage in the OCBs that promote safety (e.g., monitoring coworkers' performance) and participate in safety-related activities (e.g., health and safety initiatives, and safety committee service). Evidence supports a link between high LMX relationships and subordinates' safety citizenship behaviors (Hofmann & Morgeson, 1999; Hofmann, Morgeson, & Gerras, 2003; Kath, Marks, & Ranney, 2010). Hofmann et al. (2003) demonstrated that subordinates in high LMX relationships expanded their formal role definitions to include safety citizenship behaviors. Hofmann and Morgeson (1999) found that the association between high LMX relationships and fewer injuries was mediated by safety commitment and safety communication; that is, high LMX relationships facilitated greater commitment and more effective communications, which in turn assisted in reducing injury likelihood.

LMX frequently mediates between organizational antecedents and employee experience (Dulebohn, Bommer, Liden, Brouer, & Ferris, 2012). In their meta-analysis, Dulebohn et al. (2012) found a significant relationship between transformational leadership and LMX (effect size 0.73), with LMX mediating such employee behaviors as OCBs. Thus, transformational leaders were able to build high LMX relationships with their employees, based on trust, loyalty, and integrity. Leaders who displayed these values in their social exchanges with employees were likely to be viewed as concerned and committed to their workforce, which is reciprocated by employees through safe working (Dulebohn et al., 2012). Research has shown that high LMX is associated with employees raising safety concerns with their supervisors (Kath et al., 2010). Thus, managers can enhance safety and reduce the likelihood of injuries by fostering close, high-quality relationships with their employees. LMX has been found to mediate the effects of transformational leadership, but as being even more effective as a mediator of contingent reward behavior from leaders (Dulebohn et al., 2012).

9.6.3 Safety climate

Leadership has been discussed as an important antecedent of employees' perceptions of the priority of safety (i.e., safety climate). Models of organizational safety have often included a mediating role for safety climate between organizational factors (including leadership) and safety outcomes (e.g., Clarke, 2010, 2013). Empirical evidence has supported a mediation role, both at an individual level (e.g., Barling et al., 2002; Wu, Chang, Shu, Chen, & Wang, 2011; Zohar, 2003; Zohar, Huang, Lee, & Robertson, 2014) and at group level (e.g., Zohar & Tenne-Gazit, 2008). Safety climate plays an important role in transferring employees' experience of leaders' behavior into safety performance. This mediating effect extends to different forms of positive leadership, including transformational (e.g., Luria, 2008; Wu et al., 2011), empowering (Martínez-Córcoles et al., 2011), and authentic leadership (Borgersen et al., 2014).

Managers' leadership style is likely to affect how they represent their attitudes and how subordinates interpret managers' actions. Barling et al. (2002) found that the relationship between transformational leadership and occupational injuries was fully mediated by safety climate. Zohar (2002b) found that transformational leadership and contingent reward were both related to minor injuries, where the relationship was fully mediated by safety climate. This relationship was moderated by externally assigned safety priorities, such that transformational leaders generated a positive safety climate, even when safety was assigned a low priority. Contingent reward was only effective in generating a positive safety climate when safety was assigned a high priority. Transactional leadership resulted in a positive safety climate under high-assigned priority, but poor safety climate under low-assigned priority. These results suggested that transformational leaders can promote a positive safety climate, leading to fewer occupational injuries, regardless of the assigned safety priority, whereas contingent reward and transactional leadership require safety to be assigned a high priority in order to have a positive effect on safety climate (Zohar, 2002b).

Zohar et al. (2014) examined the effects of distant leadership style on truck drivers' psychological safety climate perceptions. Although drivers tend to operate largely in isolation, these lone workers still developed perceptions of safety priority through interactions with their leaders, which significantly influenced subsequent hard-braking events (indicative of near-miss traffic incidents) mediated by driving safety. Leadership style also affected the development of group-level safety climate, where shared perceptions of safety priority mediated the effects of leadership on group-members' behavior at unit-level (Zohar & Tenne-Gazit, 2008).

Although most research has focused on mediation effects, there is evidence that safety climate acts as a contextual variable, influencing the extent to which organizational factors impact employee behavior. Safety-specific transformational leadership directly shapes employee perceptions of safety in the workplace, which in turn affects employee behavior. However, such direct effects on safety climate have not been replicated when transformational leadership is nondomain specific (i.e., not specifically related to safety). For example, Kapp (2012) found that safety climate moderated the effect of (nondomain specific) transformational leadership on safety behavior, whereas general transformational leadership style only influenced behavior within a positive safety climate.

Hofmann et al. (2003) argued that safety climate acted as a moderator in the relationship between LMX leadership and safety behavior; that is, high LMX relationships only led to increased engagement in safety citizenship behaviors when safety climate was positive. In this case, safety was perceived as having high priority and so safety-related behavior was seen as a legitimate means of reciprocating a high-quality relationship with the leader. This hypothesis was confirmed by Hofmann et al.'s (2003) analysis, which showed a strong positive association between LMX and safety citizenship role definitions in workgroups with a positive safety climate, but much weaker and nonsignificant relationships in those exhibiting poorer safety climates. This study demonstrated that high LMX relationships only have beneficial effects for safety in positive safety climates, indicating that individuals with a high LMX relationship with their supervisor, who work in groups characterized by a positive safety climate, will be more likely to engage in safety citizenship behaviors (Hofmann et al., 2003). It follows that a prerequisite for any safety benefits from high LMX relationships is working in a team that has a positive safety climate.

Empirical work examining moderating effects of safety climate is relatively scarce. Extending this research is important in providing information about the boundary conditions of some relationships, and relates back to the discussion on understanding the context within which leadership takes place (Section 9.5).

9.6.4 Empowerment

Most definitions of empowerment focus on the superior–subordinate relationship in which power (i.e., decision-making authority) is delegated to employees. This power is internalized by subordinates and returned to the organization as enhanced performance. Although some theories have emphasized management practices that lead to empowerment, others have focused on empowerment as a psychological construct (Conger & Kanungo, 1988; Manz & Sims, 1980; Spreitzer, 1995; Thomas & Velthouse, 1990; Walsh, Bartunek, & Lacey, 1998). Lean production, where operations are conducted by teams, with maximum redistribution of tasks and responsibilities to the workforce, can be accompanied by increased team empowerment (Taira, 1996).

Although not usually employed as a safety initiative, empowerment has been related to improved organizational effectiveness and productivity (Hardy & Leiba-O'Sullivan, 1998). Through empowerment, workers acquire greater responsibilities and more control over their work—factors associated with better psychological and physical health (see Chapter 6). Research evidence largely supports a positive link between self-managed teams and improved safety outcomes. Hechanova-Alampay and Beehr (2002) found that degree of empowerment in self-managed teams was significantly related to both unsafe behaviors and team member injuries, such that teams that were rated as more empowered (by an independent panel of assessors), engaged in fewer unsafe behaviors, and experienced fewer injuries. Span of control was also a significant factor, indicating that workgroup size affects safety benefits, as leaders cannot cope with empowering large work teams.

As discussed in Section 9.4.1, the empowering leadership model focuses on the leader's ability to facilitate self-management within the team (Arnold et al., 2000). The development of self-management within teams has demonstrable effects on safety by creating a collaborative learning environment, in which employees work together to learn from each other in a psychologically safe environment (Martínez-Córcoles et al., 2012). Furthermore, Ford and Tetrick (2011) found that psychological empowerment was a significant predictor of safety participation, but not safety compliance (PPE use). Thus, psychological empowerment may act as a mediator in the relationship between empowering leadership and safety behavior.

9.7 Model of safety leadership

One issue to consider in relation to leadership and safety is whether specific safety leadership models are needed, or whether general leadership models are sufficient in predicting safety-related outcomes. There is evidence to suggest that safety-specific models of leadership are needed. For example, Kapp (2012) demonstrated that general transformational leadership is only effective in improving safety within the context of a positive safety climate. Furthermore, Mullen and Kelloway (2009) found that general training for transformational (rather than safety-specific) leadership failed to lead to safety improvements. This evidence suggested that leadership needs to be safety specific to have the desired effects on workplace safety. The consistency of leader's behavior is also an important consideration, as inconsistent leadership is likely to be particularly damaging for safety (Mullen et al., 2011).

Models of safety leadership have focused on understanding the nature of safety performance, and the context within which safety leadership transpires (Clarke, 2013; Zohar & Luria, 2003). Drawing on the augmentation hypothesis, Zohar and Luria (2003) argued for the application of a contingency model of safety leadership, in which transformational and transactional leadership styles were complementary, and where practice depended on the situation. The key situational variable in this model was degree of routinization, that is, rule formalization (number and specificity of rules and procedures), and activity routinization (degree of variation in problem types and difficulty in problem solving). Where routinization is high, the model suggests that transactional leadership would be most appropriate, whereas when routinization is low, transformational leadership is most suitable (see Figure 9.1). Using inappropriate forms of leadership for the situation will result in a misfit, of which the two types are as follows:

1. *Knowledge-based misfit* occurs where a transactional leader manages a workgroup whose tasks are nonroutine and where existing rules and procedures may fail to adequately address work complexity. Effective performance is based on developing a realistic mental model of the system and developing successful improvizations, and knowing when to apply rules, given an accurate assessment of prevailing hazards.
2. *Rule-based misfit* occurs where a transformational leader manages a workgroup whose tasks are routine and rules are formalized. Effective performance is based on applying appropriate rules and avoiding rule violations.

It is easy to see how knowledge-based misfits could occur, as a transactional leadership style would fail to encourage the creativity required to develop solutions to novel problems or to support the emergence of realistic mental models required to enhance safety performance. However, it is conceivable that a transactional leader of an autonomous workgroup could fare almost as well as a transformational leader, by using contingent rewards or active transactional techniques to motivate workers toward goals and allowing latitude in the means to reach those goals. Zohar and Luria (2003) argued that the rule-based misfits could result in reduced safety performance as transformational leaders would encourage innovation and safety participation where only compliance is required. Where goals are pragmatic, it has been noted that charismatic leadership could be dysfunctional (House, Spangler, & Woycke, 1991). However, while it is certainly possible that unsafe acts may result from attempting to improvize solutions where existing rules represent the most appropriate ways of working, other aspects of transformational leadership, such as individualized consideration, could be effective, even in highly routinized situations.

There is evidence that supportive supervision, where leaders demonstrate concern for subordinates' welfare and listen to safety suggestions, is related to improved safety compliance (Thompson, Hilton, & Witt, 1998), as supervisors are perceived to be fair and

	High-routinized tasks	Low-routinized tasks
Transformational safety leadership	Rule-based misfit	Participation fit
Transactional safety leadership	Compliance fit	Knowledge-based misfit

Figure 9.1 Contingency model of safety leadership. (After Zohar, D. and Luria, G., *J. Safety Res.*, 34(5), 567, 2003.)

trustworthy. A further example is from Guest et al. (1994) who investigated gangs of railway track maintenance workers performing routine maintenance work, following highly formalized rules and procedures. This study found that supervisors who made workers feel valued and treated them fairly, managed groups with a better safety record (Guest et al., 1994). This study illustrated how transformational leadership can lead to improved performance, even in a highly routinized environment.

Zohar and Luria's (2003) model suggested that transformational leadership is primarily associated with safety participation, while transactional leadership is primarily associated with safety compliance. To some extent this suggestion was supported by Clarke's (2013) meta-analysis of safety leadership style. A structural equation model showed that transformational leadership had a direct effect on safety participation (but not on safety compliance), and that active transactional leadership had a direct effect on safety compliance (but not on safety participation). Clarke (2013) argued that given the nature of safety performance (depending on both compliance and flexibility), safety leadership (particularly in safety-critical organizations) required a combination of both transformational leadership and active transactional leadership.

Griffin and Hu (2013) developed a safety leadership model comprising two categories of leader behavior, which reflected aspects of both transformational and transactional leadership: safety inspiring (degree to which a leader presents a positive vision of safety that is appealing and inspiring); and safety monitoring (degree to which a leader acts as an external monitoring source to assist employees to be aware of their unsafe actions). Safety inspiring is similar to the dimension of inspirational motivation (transformational leadership style) and safety monitoring is similar to transactional leadership. Griffin and Hu (2013) found that safety inspiring was significantly associated with safety participation (but not with safety compliance) and that safety monitoring was significantly associated with safety compliance (but not with safety participation). They also found a significant interaction between safety monitoring and safety learning in relation to safety participation; such that safety monitoring was significantly associated with participation in situations highly conducive to learning (Griffin & Hu, 2013). Therefore, leaders can use monitoring behavior effectively when employees are encouraged to learn from their errors.

Most conceptualizations of safety leadership still draw their theoretical framework from the transformational–transactional model. However, in their criticism of this model, Van Knippenberg and Sitkin (2013) highlighted the need for new models of (safety) leadership that better reflected everyday life. One model of safety leadership, focusing largely on defining those behaviors specifically linked to safety outcomes, is the SAFER model developed by Wong, Kelloway, and Makhan (2015). This model might be viewed as an "everyday model" of leadership, which can be used as a tool to help design interventions targeting leader behavior.

9.8 Leadership development, training, and other interventions

Kelloway and Barling (2010) reviewed the use and effectiveness of interventions that targeted leadership behavior as a means of improving occupational health and safety in organizations. They found that the use of leadership interventions was relatively scarce, but that leadership development (usually in the form of training) could be an effective intervention. Avolio, Reichard, Hannah, Walumba, and Chan's (2009) meta-analysis revealed that leadership interventions were generally successful in changing leader behaviors (the effect size 0.41 for leadership training effectiveness). For example, using half-day workshops to train managers in transformational leadership techniques, Barling, Weber, and Kelloway (1996) found that employees reported a significant increase in transformational leader behaviors 3 months later. Longitudinal research has also provided evidence that managers and supervisors can be trained to use leadership styles that encourage safe behavior among employees (Zohar, 2002a). Intervention studies in occupational safety have focused on either training managers to use transformational leader behaviors (e.g., Mullen & Kelloway, 2009) or enhancing supervisory communications with employees around safety issues (e.g., Kines et al., 2010; Zohar & Polachek, 2014). In both cases, the interventions target leader behaviors, which influence employees' perceptions, attitudes, and behaviors toward safety.

Mullen and Kelloway's (2009) intervention study randomly assigned managers in health care organizations to one of three groups: (1) safety-specific transformational leadership training; (2) general transformational leadership training; (3) no leadership training (control group). The leadership training comprised half-day group workshops in which participants learned about transformational leadership and how leader tactics could be used on a daily basis. Following the intervention, the leaders who received the safety-specific transformational leadership training reported significantly increased self-efficacy and more positive attitudes toward safety. Furthermore, employees of leaders trained in safety-specific transformational leadership reported that their leaders demonstrated more transformational behaviors and also reported more positive perceptions of safety priority (Mullen & Kelloway, 2009). The latter is an important finding as it demonstrates the cascading effect of leadership training, whereby changing leader behaviors in key managers has a widespread effect via safety climate.

Kines et al.'s (2010) construction industry intervention study included five work gangs (two intervention groups, three control groups). Foremen in the two intervention groups received training and bi-weekly feedback on their verbal safety exchanges with workers. Employee safety climate questionnaires were completed, and experience sampling methodology and onsite observations monitored leader behavior over a 42-week period. It was found that verbal safety exchanges had increased significantly from baseline to follow-up. While significant increases in onsite safety were observed in both intervention groups, employee safety climate improved in only one group. However, there were no significant changes in the control groups (Kines et al., 2010).

In an intervention over a 12-week period, Zohar and Polachek (2014) randomly assigned supervisors working in a midsized heavy manufacturing plant into experimental and control groups, collecting feedback on the supervisors' performance in relation to safety, productivity, and teamwork from their subordinates regarding daily exchanges on safety. Safety exchanges were indicative of changed safety priorities, and improved safety communication with employees resulted in corresponding changes in safety climate, safety behavior, subjective workload, and measures of teamwork. In addition, safety audit data revealed that the level of safety had improved. These results were observed only in the experimental groups, with no change occurring in the control groups (Zohar & Polachek, 2014).

While examples of effective leadership interventions exist in the literature, a number of moderating factors can influence the extent to which behavioral and cultural change is achieved. Luria, Zohar, and Erev (2008) examined the moderating effect of employees' visibility in the workplace. These authors implemented a similar intervention to that described by Kines et al. (2010), where the aim was to increase managers' safety exchanges with employees in five manufacturing plants. Managers whose employees were readily observed (in a high-visibility work environment) demonstrated a greater increase in safety communications than did managers whose subordinates were less readily observed (in a low-visibility work environment) (Luria et al., 2008). Thus, in judging whether a leadership-based intervention would be most appropriate, it is important to consider contextual variables (e.g., physical working conditions).

Other identified contextual variables affecting the success of safety interventions have included the quality of the relationship (high/low LMX), and degree of trust between managers and employees (Cox, Jones, & Rycraft, 2004; DePasquale & Geller, 1999). Given the moderating role played by trust in the leader, leadership interventions are likely to be less effective when the existing relationship between managers and employees is characterized by low trust (Conchie & Donald, 2009). Therefore, to create a favorable climate for effective behavioral and cultural change, safety interventions should include measures to enhance the relationship between managers and employees to allow for open communication, trust, and perceptions of leader integrity.

Most research addressing the nature of safety leadership has focused on supervisors' leadership style, with little attention paid to senior managers. Thus, caution must be exercised when extending results from first-line managers to those higher in organizational hierarchies. Examining supervisor support separately from management support for safety, Thompson et al. (1998) found that whilst both were significantly related to safety behavior, each played a slightly different role. Supervisor support was more closely related to safety compliance, whilst management support was more strongly associated with safety conditions. Clarke (1999) showed that supervisors' and managers' safety attitudes can differ significantly, and moreover, that both levels are viewed as significantly different from a workers' perspective, suggesting that such perceptual differences may lead to communication difficulties. Yule (2002) found that larger differences between leaders' views of their own leadership style and those of their subordinates were significantly associated with higher injury rates.

Although leadership interventions are generally more effective at supervisory levels (effect size 0.69) compared to higher level management, Avolio et al. (2009) found that interventions could still be effective when targeted at senior managers (effect size 0.51). This would imply that there is potential for leadership interventions to encompass multiple levels of management, rather than being restricted to supervisors (Kelloway & Barling, 2010).

9.9 Conclusions

Much research has emphasized the importance of management's role in organizational safety. As managers' safety attitudes are important in shaping an organization's safety culture (see Chapter 10) it is essential that senior managers are genuinely committed to improving safety and have sufficient competence to implement this commitment in policies and practice. This chapter has also illustrated how managers' leadership style can exert a significant effect on employees' perceptions, attitudes, and behavior, which impacts safety climate.

Even the most rudimentary leadership style at first-line level can have positive effects for safety if it begins to establish trust between supervisors and workers—for example, keeping promises, treating workers fairly, and engaging in clear and unambiguous communication. Effective communication and competent decision making is critical for developing employees' trust in their managers. If this kind of relationship can be fostered at local level, then trust can be transmitted throughout an organization (Whitener, 1997). Trust in senior managers and their safety policies can be developed through positive relationships between workforce and first-line managers. Positive leadership (e.g., transformational, authentic, ethical) has beneficial effects on workplace safety, particularly through the development of safety climate and employees' engagement in safety activities (safety participation). Many aspects of transformational leadership style aid effective group functioning; for example, developing novel solutions to problems, engaging in safety OCBs, and striving for a high level of safety performance. Active transactional leadership can be an effective style, particularly in safety-critical environments, given its emphasis on proactive monitoring and recovering errors before they affect safety adversely. However, while leadership interventions might profitably focus upon developing practices that characterize a transformational and/or active transactional style, there is also a need to eliminate passive leadership practices, which have deleterious effects on safety.

Demonstrating that both managers and workers could underestimate the importance of safety to the other group, Clarke (1999) found that greater information sharing can help to reduce such perceptual differences, and to foster workers' trust in management. Similarly, Flin (2003) argued that it is not always the case that senior managers lack commitment to safety, but that sometimes the workforce do not recognize that commitment. Thus, it may be necessary to focus upon improving the communication of senior management commitment throughout an organization. Flin (2003) described upward appraisal as a tool for identifying communication failures, where one senior manager, and managers at the next level down, participated in an exercise that included a workshop to discuss results, which led to successful behavioral changes for middle level managers. Management training can also have positive benefits; for example, Stokols, McMahan, Chiltheroe, and Wells (2001) examined effects of a management training program (involving role-playing exercises and time for group discussion among participants from several companies) in 48 SMEs (compared with 46 control companies). The authors found that, compared with controls, there were significantly higher levels of corporate regulatory compliance over the following 12 months. However, due to lack of reliable injury data, no relationship could be demonstrated with safety outcomes (Stokols et al., 2001).

Employees' perceptions of managers' commitment to safety is a major determinant of safety climate. These perceptions are affected by leadership style, effectiveness of organizational work practices, and safety systems, and the quality of communication between managers and workforce. As little research has examined the mechanisms by which senior managers influence corporate safety performance, this area requires more research attention.

chapter ten

Safety culture

The first use of the term *safety culture* is generally ascribed to the International Atomic Energy Agency (IAEA, 1986) report of the Chernobyl nuclear disaster, the cause of which was attributed to a breakdown in the organization's safety culture. Subsequently, a number of other major disasters that were subject to detailed independent public inquiry also revealed the significant role played by organizational and social factors (Reason, 1990). The term safety culture was quoted by several inquiry reports as an explanation for the way that a combination of managerial, organizational, and social factors contributed to the disasters. These included the Kings Cross underground station fire (Fennell, 1988), the Clapham Junction rail disaster (Hidden, 1989), and the North Sea platform Piper Alpha explosion (Cullen, 1990). The idea of safety culture was highlighted for a broader range of organizations, including those involved in transportation and public safety, as well as the nuclear industry. It has continued to appear as a substantive issue in accident inquiry reports over the past 30 years. For example, the term appeared 10 times in the Special Commission of Inquiry Interim Report into the Waterfall rail disaster (McInerney, 2004), 70 times in the Glenbrook Rail Accident report (McInerney, 2001), and 26 times in the President's Commission Report into the *Deepwater Horizon* accident (National Commission, 2011). The concept of safety culture has also generated a considerable amount of academic research, debate, and discussion (e.g., Clarke, 2000; Cox & Flin, 1998; Glendon, 2008; Guldenmund, 2000, 2010).

Giving a high priority to safety issues was defined by the IAEA as being indicative of a safety culture (IAEA, 1986; INSAG, 1991). The IAEA (1986) defined safety culture as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, [nuclear] safety issues receive the attention warranted by their significance." A variety of definitions has been proposed, including a widely cited working definition suggested by the UK Health and Safety Commission: "the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management" (HSC, 1993, p. 23). Pidgeon (1991) considered culture to be a shared meaning system and safety culture to be "the constructed system of meanings through which a given people or group understand the hazards of the world" (p. 135). As its definition depends on individuals' perceptions being shared within a group, organizational, or societal context, safety culture is essentially a social phenomenon. This feature is reflected in many definitions; for example, Cox and Cox (1991), and HSC (1993) both referred to "shared perceptions of safety" and Cooper and Phillips (1994) to "a collective commitment of care and concern." Definitions of organizational culture also emphasize its shared or social nature (Bate, 1984; Schein, 1985). However, Turner (1991) noted that while safety culture has important social dimensions, it also has a technical aspect, which should not be overlooked; he emphasized the nature of safety culture as sociotechnical rather than wholly social.

Mearns, Whitaker, and Flin (2003) argued that safety culture is important because "it forms the context within which individual safety attitudes develop and persist and safety behaviors are promoted" (p. 642). Empirical work within this perspective has focused upon examining safety attitudes (often restricted to employees, rather than managers) as being indicative of an organization's safety culture (Cox & Cox, 1991; Cheyne, Cox, Oliver, & Tomás, 1998; Lee, 1998). Safety culture acts as a frame of reference for work behavior; that is, it determines what kinds of behavior are acceptable or will be rewarded by an organization, thereby helping to shape behaviors that employees routinely engage in. For example, Merritt and Helmreich (1996) viewed safety culture primarily as a frame of reference within which company safety policy and regulations are interpreted. Guest, Peccei, and Thomas (1994) noted that it "will include the way these issues [risk and danger] are viewed and the priority attached to them in determining day-to-day behavior" (p. 2). Similarly, Cooper and Phillips (1995) stated that safety culture is reflected in "the dynamic interrelationships between members' perceptions about, and attitudes toward, organizational goals; members' day-to-day goal-directed behavior; and the presence and quality of organizational systems to support goal-directed behavior" (p. 6). Williamson, Feyer, Cairns, and Biancotti (1997) suggested that safety culture could thereby "predict the way employees behave with respect to safety in [a particular] workplace" (p. 16).

It has been noted that although the concept of safety culture was developed to account for organizational injury rates, it is increasingly used to account for injury involvement at an individual level (Mearns et al., 2003). In the sense that, safety culture influences individual employees' behavior, this would suggest that there could be a role for safety culture in predicting worker injury involvement. Organizational safety culture, and how it is interpreted at local level, could affect the development of employees' behavioral expectations. While the underlying safety culture will influence employees' general behavioral expectations, more localized influences, such as a supervisor's interpretation of safety policies, could also have a powerful effect. Group safety climate, which is more susceptible to transition and change, will also influence behavior; indeed, safety climate has been defined in terms of acting as "a frame of reference for guiding appropriate and adaptive task behaviors" (Zohar, 1980, p. 96). There can be friction between espoused policies and procedures endorsed by an organization (embodying fundamental beliefs regarding safety), and interpretations of local managers and supervisors (e.g., under production pressure, supervisors may turn a blind eye to safety rule violations).

One difficulty associated with using the term culture is that it may contribute no additional meaning to another term with which it may be paired, which tends to dilute its conceptual utility. For example, the term blame culture is frequently used. While blaming may be a perceived aspect of a given culture, it will not be the only feature, and in an organization in which people may be blamed for incidents, it is unlikely to be helpful to have the whole organizational culture labeled in this stereotypical way. The problem may be one of everyday usage taking over more conceptual use.

This chapter addresses safety culture and the related concept of safety climate. Safety culture refers to the fundamental underlying beliefs and values of a group of people in relation to risk and safety. While much has been written about safety culture, there has been relatively little focus on ways of improving it, despite widespread recognition that a positive safety culture is a prerequisite for successfully managing safety risks. In this chapter, the nature of safety culture and the difference between safety culture and safety climate is discussed; followed by a review of theoretical models that elucidate mechanisms linking safety culture with safety performance, including a discussion of high-reliability organizations; measurement issues and finally, ways to promote a positive safety culture are explored within the context of a risk management approach to safety.

10.1 Nature of safety culture

A distinction has been made between safety culture as something that an organization is and something that an organization has (Cox & Cox, 1996; HSC, 1993; Reason, 1997), reflecting two broad and contrasting perspectives: the interpretive (or symbolic) versus the functionalist approach (Alvesson, 2001; Richter & Koch, 2004; Waring, 1996; Waring & Glendon, 1998).

10.1.1 Interpretive approach

The interpretive approach assumes that organizational culture is an emergent complex phenomenon of social groupings, which serves as the prime medium for organizational members to interpret their collective identity, beliefs, and behaviors. Culture should be understood as "an ordered system of meaning" (Haukelid, 2008). Organizational culture is not owned by any single group but is a unique creation of all the organization's members. From assumptions characterizing the interpretive approach to organizational culture, it follows that managerial attempts to manipulate culture (e.g., driving rapid organizational change) are likely to fail because of the application of an inadequate model of processes that they are attempting to manipulate. Cox and Cox (1996) described safety culture as an emergent property of the organization as a system; and several authors have used the phrase derived from *gestalt* psychology "greater than the sum of its parts" (Cox & Cox, 1996; Lee, 1998; Reason, 1997). Gherardi and Nicolini (2000) observed that safety culture emerged from operational practice within a community. These interpretive standpoints assume the following points (Waring, 1996):

- Culture is a complex outcome of all people in the organization (not just senior managers)
- Strategy supports culture (not vice versa)
- Culture cannot be trained or sloganized into people
- Culture change cannot be engineered quickly, but is by slow learning

An implication of the interpretive view is that culture cannot be considered as a simple thing that can be "bolted on" to an organization (Turner, Pidgeon, Blockley, & Toft, 1989); safety culture is not easily developed, changed, or manipulated. This perspective contrasts sharply with a functionalist view suggesting that culture is amenable to management control as it is essentially an expression of organizational strategy. Waring (1996) emphasized the importance of understanding the influence of organizational power relations and politics on organizational (and safety) culture. These aspects are critical to organizational learning (Pidgeon, 1997). Thus, an interpretive approach to culture change focuses upon the importance of such contextual factors and emphasizes that change cannot be achieved through structural changes per se.

Adopting a modified form of symbolism, Richter and Koch (2004) noted that an interpretive approach involved people constructing events, which are reproduced by networks and symbols that enable shared meanings and actions. They maintained that success depended on whether change strategies were meaningful to local actors. Ambiguity refers to potential for irreconcilable differences in meanings and symbolic interpretations (Alvesson, 1993; Frost, Moore, Louis, Lundberg, & Martin, 1991).

10.1.2 Functionalist approach

The assumption underlying the functionalist approach is that organizational culture is an ideal to which organizations aspire and that it can be manipulated to serve corporate interests. The prime function of organizational culture is to support management strategies and systems; this is premised on the assumption that it can be reduced to relatively simple models of prediction and control (Waring, 1996). This approach primarily aligns organizational culture to support managerial ideology, goals, and strategy, in extreme cases involving managerial use of culture to coerce and control. Cooper and Phillips (1995) argued that because safety culture is expressed in goal-directed behavior, this allows actions to be formulated that shape, change, or manage safety culture. Reason (1997) suggested that safety culture could be socially engineered by "identifying and fabricating its essential components and then assembling them into a working whole" (p. 192); furthermore, he criticized interpretive approaches, comparing their perspective on culture change as, "akin to a religious conversion," suggesting rather that "there is nothing mystical about it . . . [a safe culture] can be acquired through day-to-day application of practical down-to-earth measures" (Reason, 1998, p. 305).

The interpretive/functionalist dichotomy underlies the debate as to whether all organizations can be said to have a safety culture or, as Reason (1997) argued, "like a state of grace, a safety culture is something that is striven for but rarely attained" (p. 220). This functionalist position is also maintained by Hopkins (2005), who equated safety culture with a culture of safety, maintaining that only organizations with an overriding commitment to safety can be said to have a safety culture. Some representatives of an integration perspective link this with managerial prerogatives and top-down attempts to change culture (Deal & Kennedy, 1986; Hofstede, 1991; Peters & Waterman, 1982). However, Pidgeon (1998) considered that it is unrealistic for culture change to be brought about by top-down safety management measures. A top-down approach is also implicit in Gadd and Collins' (2002) safety culture literature review, and Hale and Hovden's (1998) analysis. While Reason's (1997) use of safety culture to refer to effective safety culture is an absolutist position, he also expressed sympathy with the Health and Safety Commission's definition, which is a relativist position. Reason (1997) aligned himself with the functionalist position, citing Hofstede (1994), although Hofstede's own position is something of an amalgam of functionalist and interpretive approaches.

A functionalist view favors a regulatory approach that organizations can change their existing safety culture to one that can result in improved safety performance, while the interpretive view indicates that such a change will be difficult to achieve and cannot be imposed by senior management. In practice, many organizations display elements of both approaches. For example, by adopting risk-management practices, an organization invokes functionalist aspects of its safety culture; while a more interpretive side may be revealed by individual and group commitment to open-ended learning from past mistakes, such as those leading to injuries (Glendon & Stanton, 2000).

10.2 Relationship between safety culture and safety climate

Of the relationship between safety climate and safety culture, Mearns, Whitaker, and Flin (2001) considered that "safety climate can be defined as the manifestation of the underlying safety culture in safety-related behaviors of employees and in employees' expressed attitudes" (p. 771). While culture implies a notion of residing within an organization, climate has more passive connotations, reflecting attitudes and perceptions of organization members to both internal (e.g., management actions) and external (e.g., economic) influences (Glendon, 2005). Gadd and Collins (2002) reviewed the safety culture and safety climate literature, mainly from 1998 (locating 78 references for this period), and explored links between safety culture and safety performance. They viewed safety climate as the current surface features of safety culture that are discerned from employees' attitudes and perceptions (Flin, Mearns, O'Connor, & Bryden, 2000). Safety climate might be viewed as the 'measurable aspect' of safety culture (Zohar, 2008). Noting the dearth of studies addressing the stability of safety culture over time, Mearns et al. (2001) cast doubt on whether safety culture (or climate) is stable over time.

Within the literature, the term *safety climate* has often been used interchangeably with safety culture (Guldenmund, 2000), although this term has a different history and has been studied independently (Clarke, 2000). Some authors consider climate to be one manifestation of culture, where climate reflects aspects of an organization's culture that are visible or measurable; climate, being a more superficial concept than culture, describes important features of an organization's current state, such as the perceived quality of an organization's internal environment. Culture is often seen as being long term and strategic, while climate is short term and tactical. Scaled dimensional measures are the most popular way of measuring organizational climate and many of these have been devised. Dimensions typically assessed include physical environment, supervision, top management, and coworkers (Parker et al., 2003), flexibility and innovation, responsibility, motivation to achieve, management support, clarity, self-expression, and challenge (Carr, Schmidt, Ford, & DeShon, 2003). Most researchers in the field advocate maintaining a distinction between (safety) culture and (safety) climate (e.g., Cox & Flin, 1998; Glendon & Stanton, 2000; Guldenmund, 2000; Hale & Hovden, 1998; Hopkins, 2005; Schein, 1992). Climate is generally taken to be a manifestation of culture (Mearns et al., 2001), while culture in its various configurations, including safety, is taken to be more abstract, multilayered, stable, and global. Hale and Hovden (1998) argued for using the term safety culture within a structural context, reserving safety climate for nonstructural contexts (e.g., human resources, political, and symbolic). Figure 10.1 shows one view of the relationship between organizational culture and climate (Glendon & Stanton, 2000). In this model, organizational culture is represented at three levels as well as having breadth and time dimensions. Organizational climate

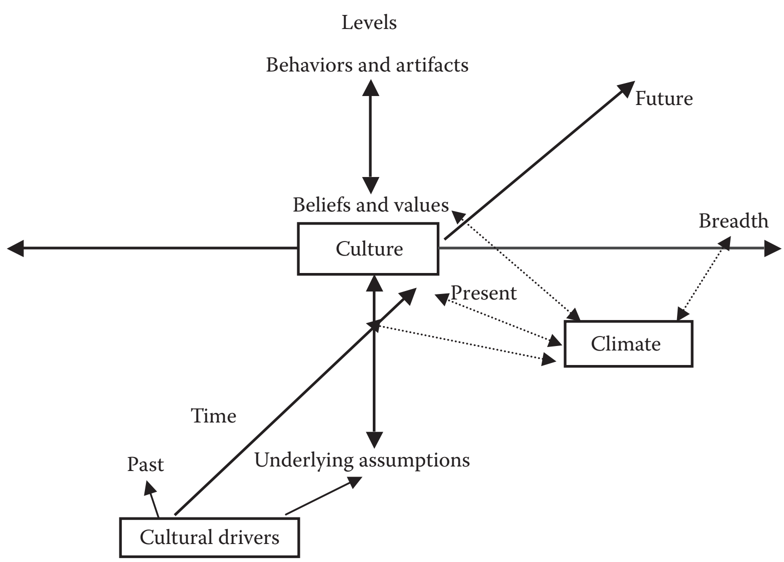


Figure 10.1 Relationship between (safety) culture and (safety) climate. (After Glendon, A.I. and Stanton, N.A., *Safety Sci.*, 34(1–3), 193, 2000.)

measures can access certain components of the dimensions of organizational culture, but across a limited range; for example, those relating to member attitudes, beliefs, and perceptions reflect cultural breadth at the time that a survey is undertaken and perhaps a little in the past as well. However, as organizational culture change is generally taken to occur over a period of years, the timeframe for assessing culture must reflect this time dimension.

10.3 Theoretical models of safety culture

Despite widespread recognition of the importance of safety culture, the concept remains theoretically underspecified (Clarke, 2000). Some scholars (Glendon & Stanton, 2000; Guldenmund, 2000) have adopted a model of safety culture that is analogous to Schein's (1985) model of organizational culture, with core, intermediate, and surface layers. Other attempts to develop an understanding of safety culture have adopted different theoretical roots, which may create insights into the mechanisms by which safety culture affects safety-related outcomes; these include Cooper (2000), Geller (1991, 1994, 1996), Reason (1997), and Westrum (1993, 2004).

10.3.1 Organizational culture approach

Glendon and Stanton (2000) described the notion of safety culture as having arisen largely from ideas about organizational culture, such that safety culture is regarded as "those aspects of culture that affect safety" (Waring & Glendon, 1998). Many definitions highlight features that safety culture shares with organizational culture (Clarke, 2000; Clarke & Cooper, 2004; Guldenmund, 2000). Organizational culture has been described as being multilayered, with three levels commonly distinguished: deepest level (core assumptions), intermediate (beliefs and values), and surface manifestations (norms and artifacts) (Rousseau, 1988, 1990; Schein, 1985). Safety culture has also been described as existing at differing levels, being, "the specific set of norms, beliefs, roles, attitudes, and practices within an organization which is concerned with minimizing exposure of workers, managers, customers, suppliers, and members of the general public to conditions considered to be dangerous or injurious" (Turner, 1991, p. 241). In reviewing the literature on organizational and safety culture, Guldenmund (2000) defined safety culture as, "those aspects of the organizational culture which will impact on attitudes and behavior related to increasing or decreasing risk" (p. 251). Guldenmund conceptualized safety culture as having the following three levels:

1. *Outer layer*: Artifacts, which are visible, but hard to comprehend in terms of underlying culture, for example, statements, meetings, inspection reports, and posters.
2. *Middle layer*: Espoused values/attitudes regarding hardware, software, people, and risks, which are relatively explicit and conscious, for example, attitudes, policies, procedures, and job descriptions.
3. *Core*: Basic assumptions regarding the nature of reality and truth, time, space, human nature, human activity, and human relationships, which are mainly implicit and have to be deduced from artifacts and espoused values, as well as through observation.

Models of this nature attempt to retain the holistic and integrative nature of organizational culture. Measurement methodologies advocated by this approach emphasize the need to tap into the multiple layers of safety culture, using triangulation.

10.3.2 Total safety culture

Geller (1991, 1994) proposed the concept of total safety culture (TSC), which is based on a behavioral approach to safety. This concept emphasizes achieving TSC status through implementing applied behavioral techniques. Geller (1994) defined a TSC as an environmental setting where, "everyone feels responsible for safety and pursues it on a daily basis, going beyond the call of duty to identify unsafe conditions and behaviors, and intervene to correct them . . . safe work practices are supported via rewarding feedback from peers and managers; people actively care on a continuous basis for safety . . . safety is not a priority that can be shifted depending on situational demands; rather, safety is a value linked with all other situational priorities" (p. 18). A TSC can be developed through coaching managers to extinguish unsafe behaviors and to encourage actively caring for safety. These techniques have been widely applied by Geller and colleagues (e.g., Geller, 1998, 2001; Geller & Glaser, 1996). The basic theoretical model underlying TSC is that of behavioral psychology, which emphasizes manipulating cues and consequences in order to reinforce desired behavior, and to eliminate undesired behavior. Although the model focuses on behavioral change, it recognizes dynamic interplay between behavior, individual, and environmental context. Behavioral change is most successful when supported by environmental and attitudinal changes. Therefore, the model incorporates the interplay between the three factors outlined below:

1. *Environment*: Including equipment, tools, machines, housekeeping, physical layout, and temperature
2. *Person*: Including knowledge, skills, abilities, intelligence, motives, personality, attitudes, and beliefs
3. *Behavior*: Including safe and unsafe work practices, complying, coaching, recognizing, communicating, and "actively caring" (exceeding the call of duty to protect another person's safety)

Summary Text 10.1 outlines the ten principles on which the TSC model is based (Geller, 1994).

Substantial empirical evidence supports positive benefits of behavioral safety programs. Geller and colleagues have reported specific success of programs designed to develop TSC status (Geller, 1998, 2001; Geller & Williams, 2001). The model has been extended to include self-management for workers who work in isolation or who are subject to little supervision (Hickman & Geller, 2003a, 2003b). Thus, workers are responsible for manipulating cues, monitoring target behaviors, and self-administering rewards. A number of studies have successfully increased safety practices using self-management techniques (Hickman & Geller, 2003a, 2003b; McCann & Sulzer-Azaroff, 1996; Olson & Austin, 2001). However, as the process is essentially subjective and potentially inaccurate, several problems are implicit in a self-management approach. Some studies have attempted to overcome these difficulties by combining self-monitoring with objective feedback, in samples of bus drivers (Olson & Austin, 2001), short-haul truck drivers (Hickman & Geller, 2003a), and miners (Hickman & Geller, 2003b).

The TSC model is essentially a control-oriented approach, where managers define and specify unsafe behavior and reward compliance. Thus, its success depends on managers being able to correctly identify critical behaviors and apply appropriate reward strategies. It also assumes a model of injury causation in which correcting unsafe work behaviors and encouraging safe workforce behaviors is sufficient to maintain a positive safety culture.

SUMMARY TEXT 10.1 10 Principles of Total Safety Culture (TSC)

The culture, not safety legislation, should drive the safety process—Employees should be motivated to achieve safety outcomes for themselves, rather than to comply with external regulators (such as OSHA).

Integrate behavior-based and person-based factors to create success—Using a behavior-based approach to safety and taking into consideration personal factors (such as attitudes, knowledge, and motivation); these two approaches should be integrated to create a TSC.

Focus on process, not outcomes—Shift focus away from outcomes (reducing work injuries) to actual behaviors; develop incentive and recognition programs to encourage personal control over individual and team behavior.

Behavior is directed by cues and motivated by consequences—Promote understanding of the behavioral model of safety and involve employees in designing and implementing behavioral intervention strategies (usually based on including cues to direct target behavior and consequences to motivate their occurrence).

Focus on achieving success, not on avoiding failure—Using positive reinforcement to promote safe behavior is more successful than monitoring losses (such as injuries), which tends to focus on failure; safety accomplishments might include, purchase of safer equipment, correction of safety hazards, or increases in safe behavior.

Observation and feedback lead to safe behaviors—Introduce an effective observation and feedback process, whereby employees observe each other's behavior and offer supportive feedback, that is, act as safety coaches; this must be based on substantial worker training and accountability.

Effective feedback occurs via behavior- and person-based coaching—Support employees in giving and receiving feedback through developing coaching skills (including persuasive speaking, active listening, ability to objectively and systematically observe behavior, ability to recognize cues and consequences, capacity to acknowledge small-win changes, and ability to use humor, build self-esteem, and reward with praise in order to gain acceptance).

Emphasis on observing and coaching—Employees not only need the knowledge, skills, and ability to use observation and coaching, but also the motivation.

Emphasize self-esteem, belongingness, and empowerment—Increasing the likelihood of safe behavior through increasing personal self-esteem (feelings of being valued), team cohesion (feelings of belonging), and empowerment (feelings of responsibility).

Shift safety from a priority to a value—Ensure that safety is linked consistently with all aspects of the job (including productivity and profitability), rather than as a priority (as priorities can change).

Source: After Geller, E.S., *Professional Safety* 39, 18, 1994.

The model does not indicate that any change is required at hierarchical levels above the workforce. Despite acknowledging interplay between person, behavior, and environmental factors, the major driver of cultural change is located within the behavioral domain. Proponents of behavior-based safety programs point to their relative ease of implementation, as they require little formal training and can be administered by on-site managers or supervisors (Cantor, Boyce, & Repetti, 2004). However, successful use of such approaches depends not only on their application, but also on the cultural maturity of the organization (see Section 10.3.5). Thus, while improved safety culture may be an outcome of behavior-based interventions, to some extent, a baseline level of safety culture is also a prerequisite for improvement. The TSC model incorporates some factors associated with occupational safety highlighted in other chapters, including the importance of safety motivation, team cohesion and empowerment, and integrating safety into all aspects of a job. Some evidence suggests that, under certain circumstances, behavioral safety programs can lead to a sustained improvement in safety culture over time.

10.3.3 Safety culture: An informed culture

Reason (1997) conceived of safety culture as "the engine that continues to propel the system toward the goal of maximum safety health, regardless of the leadership's personality or current commercial concerns" (p. 195). Thus, unlike safety climate, which can be significantly affected by current conditions, including the state of the economy and current leaders, safety culture is an underlying driving force that has a degree of constancy. Its power is derived from maintaining a high degree of vigilance (e.g., "not forgetting to be afraid") and avoiding complacency. An *informed* culture, characterized by collecting safety-related data and conducting proactive checks, comprises the four components described below:

1. *Reporting*: Encouraging feedback and workforce participation. This might be achieved through confidential reporting systems that provide indemnity against disciplinary proceedings, ensure confidentiality or de-identification, and maintain separation between those handling reports and those imposing sanctions. Reporting systems with these characteristics aid development of trust between workers and managers. Reports should be easy to make and provide timely and useful feedback.
2. *Just*: People are rewarded for providing safety-related information, but are clear on differences between acceptable and unacceptable behavior (suggesting that an appropriate blame culture component might be preferable to a no-blame orientation).
3. *Flexible*: Adaptable in the face of hazards or danger. Flexibility can be achieved by decentralizing control and by using diverse teams that can operate autonomously.
4. *Learning*: A willingness to learn the right lessons and to implement solutions.

It is important that learning takes place in the upper echelons of management and throughout the organization. This approach to learning is embodied within the *learning organization*, in which there is a focus on facilitating the learning of all workers and by being alert to the need for continuous transformation (Pedlar, Boydell, & Burgoyne, 1989). In essence the aim is to create a culture of continuous learning for all workers. Systematic self-analysis of an organization's experience, especially its mistakes, is a necessary prerequisite for an organization that wants to be a learning organization. Sharing information about key aspects of the strategic direction of the organization and important operational

SUMMARY TEXT 10.2 Characteristics of a Learning Organization

Adopt a systems perspective when examining the various strands of interdependent action within the organization. Systems thinking also encourages employees to keep the big picture in mind and to develop sensitivity to the external environment.

Be highly focused in effort, be patient, and be introspective and objective when confronting assumptions and ideas underpinning present practices. Double-loop learning, which can amount to adopting a critical perspective whereby things are challenged, would take place here if members use feedback to test the validity of current values and practices. This contrasts with single-loop learning, where the aim is to correct errors that arise from using particular operating instructions.

Place value on self-development and continuous development, so that expertise is allowed to flourish and problem solving is enhanced. There is a climate characterized by the generation of knowledge and its widespread dissemination, as well as a willingness to modify worker behavior in response to new knowledge and insights.

Develop shared views of where the organization is now and develop a shared vision of the future, reflected in members developing a common purpose and commitment with respect to the primacy of learning in the organization. Leadership is crucial in promoting a shared vision.

Promote team learning where members come together and freely share ideas and opinions in order to improve problem solving. An important principle is putting new knowledge and insights into action. These could be innovations in the way the company is organized and in the management of people, leading to creativity and flexibility in the contribution of the human resource.

Source: After McKenna, E.F., *Business Psychology and Organisational Behaviour*, 4th edn., Psychology Press, Hove, England, 2006.

issues in connection with policy implementation, together with information from stakeholders (e.g., suppliers and customers), is heavily underlined. Managerial qualities of a learning organization have been described and operationalized (e.g., Senge, 1990; Senge et al., 1999) as outlined in Summary Text 10.2.

10.3.4 Reciprocal safety culture model

Maintaining that many researchers have over-emphasized the importance of shared perceptions and attitudes toward safety, Cooper (2000) defined safety culture as, "the product of multiple goal-directed interactions between people (psychological), jobs (behavioral) and the organization (situational)" (p. 118). Cooper (2000) drew an analogy between this model of safety culture and Bandura's social learning theory (1977), which highlighted interactive relationships between person, behavior, and situation (echoing the person–behavior–environment model underlying Geller's TSC model described earlier). Thus, safety culture is the product of interactions between the three components outlined below:

- *Safety climate*: Internal, psychological factors relating to the person, including attitudes and perceptions; this element of safety culture can be assessed using safety climate questionnaires
- *Safety-related behavior*: Ongoing and observable behavior; this element can be measured through such techniques as behavior sampling and observation
- *Safety-management system*: Organizational policies, practices, and procedures, and management style (the situation); this element can be measured with objective safety audits

The model reflects the dynamic nature of safety culture as it emphasizes interrelationships between the three components. Investigations into influences upon safety culture might usefully focus on any of the interactions between safety climate (person), safety management system (situation), and safety-related behavior, or how one element is conditional on the other two. It also supports a triangulated approach to measuring safety culture. Although there is no empirical test of the three-way interaction between these elements, some studies have focused on relationships between two of them. Glendon and Litherland (2001) conducted a safety climate survey and behavior sampling of workers' safety critical behaviors, but failed to find a significant relationship. However, evidence of a significant direct relationship between safety climate and behavioral observations, undertaken as part of a behavioral safety initiative, was reported by Cooper and Philips (2004). The model was developed further by Choudhry, Fang, and Mohamed (2007) for application in the construction industry.

10.3.5 Sociotechnical model of safety culture

As noted earlier, Turner (1991) emphasized the importance of recognizing the sociotechnical nature of safety culture, rather than developing a model of safety culture that is wholly or primarily social in nature. From a sociotechnical systems perspective, it is important to take account of the interplay between people, technology, and organization, in developing a model of safety culture (Grote & Künzler, 2000). Safety culture depends on two key assumptions: (1) that social and technical subsystems must be jointly optimized; and (2) that the system has the capability to control variances at source; these two assumptions lead to an emphasis on effective safety management systems (that integrate social and technical aspects), and self-regulation of teams (which are able to manage themselves). Grote and Künzler (2000) described the following characteristics of the safety culture model:

- *Material characteristics* (*which are visible, but difficult to decipher*): Integration of safety into organizational structures and processes, and joint optimization of technology and organization
- *Immaterial characteristics* (*which are hidden, and taken for granted*): Values and beliefs that safety should be integrated into all work processes, and norms regarding sociotechnical design principles, such as automation, trust, and control

Grote and Künzler (2000) used a number of methods to measure safety culture, including questionnaire, expert interviews, and workplace observations during safety audits. They found that these methods could be used to provide organizations with an enhanced awareness of existing safety norms and values, and to assist auditors gain a better understanding of organizational safety as part of their assessments. This approach was validated in a further study by Grote (2008).

10.3.6 Cultural maturity model

Westrum (1993, 2004) developed a typology of safety culture within organizations based on how they manage safety-relevant information; this comprised three different types of organization:

1. *Generative organization*: In which information is actively sought, responsibility for safety is viewed as shared by all members of the organization, safety failures lead to investigation, and new ideas are welcomed
2. *Bureaucratic organization*: In which information may be ignored and new ideas can cause problems, responsibility for safety tends to be compartmentalized (e.g., health and safety department), but safety failures are dealt with fairly
3. *Pathological organization*: In which information may be hidden and whistle-blowers are dealt with harshly, new ideas are actively discouraged, safety responsibilities are ignored, and safety failures are covered up

A number of scandals in the UK health care sector highlighted how pathological organizations can lead to significant deficiencies in patient safety (see Summary Text 10.3).

In order to develop an effective safety culture, an organization needs to work toward becoming a generative organization. In a development of Westrum's work, Parker, Lawrie, and Hudson (2006) developed a safety culture maturity model which they validated using an interview study with senior managers from the oil and gas industry. The model defined five levels of cultural maturity, through which organizations may develop toward

SUMMARY TEXT 10.3 Failures at Stafford Hospital (UK National Health Service)

A public inquiry, chaired by Robert Francis QC, was conducted into significant failings at Stafford Hospital and the report published in 2013. The report concluded that there was a negative culture at the Hospital:

> the wider system did not react to the constant flow of information signalling cause for concern, those with the most clear and close responsibility for ensuring that a safe and good standard care was provided to patients in Stafford, namely the Board and other leaders within the Trust, failed to appreciate the enormity of what was happening, reacted too slowly, if at all, to some matters of concern of which they were aware, and downplayed the significance of others.
>
> **Executive Summary (p. 44)**

In addition to a negative culture, the report also identified issues related to: professional disengagement; failure to listen to patients; poor governance; shortage of skilled nursing staff; poor leadership; and staffing policies. Overall, the Trust was found to have prioritized its financial affairs and regulation over its commitment to patients and quality of care.

Source: Francis, R., *Report of the Mid Staffordshire NHS Foundation Trust: Public Inquiry*, The Stationery Office, London, 2013.

being generative. These levels identify not only how organizations manage safety information, but also the balance of productivity and safety, the 'feel' of safety meetings, and the level of safety commitment among the workforce: pathological; reactive; calculative; proactive; generative. Lawrie, Parker, and Hudson (2006) further validated the cultural maturity model in a quantitative questionnaire study. The model has been used successfully in industry as a means of helping organizations to develop a more effective safety culture and underpinned Shell's "Hearts and Minds" project (e.g., Hudson, 2007; see also Summary Text 10.4) and also in health care settings (e.g., Halligan, Zecevic, Kothari, Salmoni, & Orchard, 2014).

10.4 Organizational safety and subcultures

Pidgeon (1998) and Pidgeon and O'Leary (2000) emphasized the need to be aware of *subcultures*. They considered organizational differentiation into subcultures to be due to social structures and power relations, which can influence sense making in constructing different versions of reality. Hopkins (2005) considered that the right culture is needed to make safety systems work and, because culture relates to groups, organizations may have multiple cultures or subcultures. Following criticism that he had described organizational culture as a monolithic entity, Schein recast his earlier conceptualization of culture as applying at group level thus: "The culture of a group can now be defined as a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (Schein, 1992, p. 12). Hofstede (1994), Beck and Wolfson (1999), and Clarke (1999) are among those who deemed it more appropriate to address group cultures rather than organizational cultures. Other researchers have found evidence that different employee groups can hold different safety attitudes and perceptions of risk (e.g., Chute & Weiner, 1995; Pidgeon, 1998). Gadd and Collins (2002) identified subcultures as challenging the notion of an organization having a cohesive culture, for example, based upon different work and perspectives on risk.

Harvey et al. (2002) considered that it remained to be clarified whether safety culture consists of the same concepts for everybody within an organization or whether different subcultures exist. Testing for differences among 60 items between shop floor and management respondents, Harvey et al. (2002) found about half to be significant at $p < .001$. For plant differences (two plants), nearly half were significant at $p < .01$, with shop-floor workers mainly accounting for inter-plant differences and management scoring similarly. They also found significant differences between shop floor and management with respect to: commitment/responsibility/involvement, job satisfaction, management style/communication, avoidance of responsibility (worker only factor), good versus poor management (management only factor), and some differences between the two plants, mainly with respect to the workforces. Harvey et al. concluded that safety culture is more appropriately applied at a group rather than at an organizational level and that distinct subcultures existed. Compared with shop-floor employees, management had largely positive views of themselves, expressing greater commitment to safety, more involvement, and seeing responsibility for safety as their concern. Shop-floor groups had more negative views about management communication, management commitment to safety, personal responsibility for safety, and being listened to. There were also differences between shop-floor workers in the two plants. The authors identified three safety cultures and used attribution theory to explain differences between management and shop-floor groups.

SUMMARY TEXT 10.4 Shell International Exploration and Production's Hearts and Minds Safety Culture Change Program

The context for the Hearts and Minds Program on safety included the Swiss cheese model of accident causation (Reason, 1990), continuing commitment to managing safety, health, and environmental (SHE) issues, the *Piper Alpha* disaster and subsequent report (Cullen, 1990), and ISO 14001 standards.

One aim was to move beyond a management systems top-down control approach as the basis for effective SHE performance. While the program was designed to run itself as far as possible, requiring no consultants and minimal external facilitation, it was carried out in collaboration with researchers from universities in the Netherlands and the United Kingdom. The underlying philosophy was Westrum's (1993) evolutionary approach to safety culture, representing increasing trust, accountability, and information outlined in the following:

- *Pathological*—Noncaring, based upon not getting caught
- *Reactive*—Things may happen only after accidents
- *Calculative*—Based upon systems, audits, and collecting statistics
- *Proactive*—Resources available to work on problems; procedures "owned" by the workforce
- *Generative*—Chronic unease, new ideas welcomed, and safety seen as a profit center

Consistent with an incremental change approach program micro-tools to support development of an advanced safety culture needed to have the characteristics described below:

- Seek to change attitudes and behaviors, be documented, and achievable within 1 hour
- Fit with daily activities, such as toolbox talks and safety meetings
- Be used by supervisors and their crews
- Based on facts about human behavior, be fun to use, and effective

The tools were developed as workshops, described in brochures with a maximum of 12 pages. The three described below had wide applications:

1. *Risk Assessment Matrix*—Takes people through the RA (risk assessment) process so that they better understand the risks that they personally face
2. *Seeing yourself as others see you*—An upward appraisal tool to confront senior managers' safety priorities, trust, and commitment
3. *The rule of three*—To aid people's personal situation awareness

Four brochures for particular problem areas identified were as follows:

- *Rule breaking and failing to follow procedures*—Based upon research into types and causes of violations, in which participants identified violations within their areas and seek solutions toward greater compliance. Improvement could come from removing the cause of a violation.

- *Improving poor supervisory skills*—Developed from a leadership model, involving supervisors working in groups to develop practical improvement plans.
- *Working safely to eliminate unsafe acts*—Using behavior-based safety management principles to work through a sequence involving pre-contemplation (ignorance), contemplation (awareness), preparation (planning), and action (doing), plus monitoring (improvement/maintenance).
- *Driving for excellence*—Because a majority of fatalities occurred on the road, taking drivers and supervisors through workshops to deal, inter alia, with commercial pressures and expectations.

Further information regarding the Hearts and Minds Toolkit can be found at: http://www.eimicrosites.org/heartsandminds/

Source: After Bryden, R. and Hudson, P. T. K., *Safety and Health Practitioner*, 23, 51.

McDonald, Corrigan, Daly, and Cromie (2000) identified a professional subculture within aircraft maintenance organizations that spanned four organizations and differentiated between technicians and management. Technicians believed that they were responsible for aircraft safety and should exercise their professional skills and knowledge to carry out this responsibility. Management believed that technicians should follow set task procedures explicitly, while acknowledging that if all technicians did this then production would be delayed. In a study of offshore workers, Collinson (1999) suggested that groups viewed safety from the perspective of their own subculture, rather than sharing an overall view of safety. In particular, Collinson found that contract workers' terms and conditions were markedly inferior to those employed directly by the organization and that they did the most dangerous and physical work. Their work experience resulted in them becoming distanced from the organization and its safety culture, and they experienced a higher injury rate than did company employees. Collinson suggested that workers' perceptions of a blame culture had a greater effect on their behavior than did the safety culture promoted by the organization. Also in an offshore environment, Adie et al. (2005) found that the level of safety culture influenced perception of injury risk for three occupational groups studied. Compared with nonoffshore divers and offshore workers, professional offshore divers gave the lowest rating to safety culture in injury prevention. The authors noted that these workers received the bulk of their safety training as part of standardized induction, which could hinder developing a sense of safety culture, given that induction training does not cover the kinds of things learnt within organizations through experience. They suggested that, compared with the other two groups, offshore divers may be less likely to perceive safety culture as important in injury control because they received less consistent education in safety culture, due to a more short-term contract work pattern, and lower long-term acculturation. For all three groups, safety culture was less influential in perception of injury risk control than were supervisory quality and worker/diver competence. Other than safety culture, the main attributes that workers felt influenced injuries were supervisory quality, worker competency, and time pressure.

Noting the growing appreciation of differentiation and ambiguity within the organizational culture literature (e.g., Alvesson, 1993, 2001; Frost et al., 1991), Richter and Koch (2004) used multiple-method ethnographic action research in three case studies to demonstrate the extent and influence of integration, differentiation, and ambiguity with respect to safety culture. Failing to find a unified safety culture, they rejected Schein's (1992) notion of little variation within a unit, instead noting that integration in the three workplaces was a weak safety culture element, while differentiation and ambiguity were much more evident. They identified multiple safety cultures and found that cross-level interactions and impacts of macrocultures were important in fragmenting cultures within and between groups. They determined that safety cultures were being continually created as actors interacted with other internal and external actors.

Richter (2003) described an ethnographic and action research study of safety culture in three Danish organizations with the ultimate aim of implementing effective injury prevention programs that would be consistent with each organization's (sub)cultures. In Enterprise A, Richter found three safety cultures, each with a different focus, risk orientation, attitude toward injuries, and perception of the safety function. For example, in one culture the focus was on work content and production at the expense of safety, while risks were accepted as a condition of work and deemed to be controllable by skilled employees. Another safety culture was represented by work being viewed within the perspective of a long working life, risk taking was unacceptable and injuries were considered to be counterproductive. To some extent these contrasting cultures were reflected among first-line managers and top management. Enterprise B revealed four safety cultures. In one of these, risks were conceived as being connected to employees' risk taking and injuries were explained by employees' incorrect handling of the production system or by safety rule breaches, which incorporated the concept of guilt. Prevention was oriented toward controlling employee behavior while sanctions, including dismissal, were available. The primary role of the safety group was to serve a policing function. An alternative safety culture viewed risks as connected to technical failures and injuries as caused by technical errors. A third safety culture understood risks as connected to procedures and work conditions and injuries as multicausal.

Richter (2003) concluded that safety cultures that are diverse in interpreting safety issues and characterized by guilt, blame, or expert orientation, set up barriers to injury prevention. Safety cultures that are united by common themes are more likely to result in safer workplaces. The common denominator of the cultures represented in Enterprise A was mastery, which could serve as motivation to improve safety within the organization. Richter concluded that barriers to injury prevention activities included limited employee involvement in cultures characterized by behavior control, blame, or expert orientation. Cultures reflecting some common understanding, without a rigid division of labor and employee participation were more likely to provide a supportive environment for successful injury-prevention programs. Richter observed that the features outlined below characterized the more successful organization in terms of sustained injury rate reduction:

- Top management took safety seriously and provided required resources
- Employees were resourceful and were part of a participatory system
- Manager–employee relations were characterized by a degree of equity and mutual respect
- Nonhierarchical work organization with broadly based jobs that stimulated employees' problem-solving abilities

Evidence for the existence of safety subcultures within many organizations is now very strong, which is important to recognize when seeking culture change. As Pidgeon (1998) pointed out, to be effective, any culture change program must take account of existing subcultures, how they interact, and power relations between them. Antonsen (2009) argued that a safe culture is not necessarily one which is homogenous and free from conflict; indeed conflict might be considered as a safety resource as it facilitates learning. An over-emphasis on shared perceptions of safety can lead to unchallenged beliefs, where organizational members fail to speak up about safety issues, which can lead to a lack of response to threats at an organizational level. This institutionalized response to significant problems and potential threats has been described as "organizational silence" (Morrison & Milliken, 2000). As discussed previously (see Chapter 8), hierarchical status and leadership can have a significant influence on individuals' willingness to speak up within a team context. Other major factors that influence speaking up relate to psychological safety and efficacy (Morrison, 2014). The safety culture within teams is particularly important, therefore, in fostering an environment in which individuals feel both safe and empowered to speak up and voice their concerns (Detert & Burris, 2007; Morrison & Rothman, 2009).

10.5 High-reliability organizations

Reason (2000) described high-reliability organizations (HROs) as those that have intrinsic safety health; they operate in high-hazard conditions, performing exacting tasks under pressure, but maintain a low incident rate. Examples include naval aircraft carriers, nuclear submarines, and air traffic control (Bierly & Spender, 1995; Roberts, 1989, 1993; Rochlin, 1989). These organizations demonstrate characteristics of Reason's informed culture, being just (operating error management systems that focus upon identifying system failures rather than blaming individuals), flexible (normal operations are hierarchical in nature, but have the flexibility to respond to local circumstances by devolving control to experts on the ground), and oriented toward learning (workers throughout the organization are trained to recognize and manage errors; there is a willingness to learn from mistakes). A collective ability to discover and correct errors before they are able to escalate to crisis point has been described as cultures having the requisite imagination (Westrum, 1993), collective mindfulness, organizational mindfulness, or simply risk awareness, which may represent alternative ways of describing safety culture. Learning can be considered as a by-product of this process (Weick & Roberts, 1993; Weick & Sutcliffe, 2001; Weick, Sutcliffe, & Obstfeld, 1999). By way of contrast, Hopkins (2005) described a risk-blind culture as one in which front-line operators were not trained to look for possible mishaps. It has been argued that the source of high reliability in HROs is organizational culture (Weick, 1987). LaPorte (1996) identified the three components of high-reliability culture as:

1. An organizationally defined intention to provide for reliability and the seriousness of hazards
2. A set of reliability enhancing operations (including, structural flexibility, decentralized decision making, and continual search for improvement)
3. A set of fundamental values relating to group spirit, personal responsibility, and the importance of operational experience and expertise

Mindful organizing involves preoccupation with failure, meaning, for example, that long periods without incident, instead of breeding complacency, generate a search for errors, lapses, and possible routes to major failures. HROs have well-developed near-miss reporting systems; that is, well-developed reporting cultures (Reason, 1997). They are also reluctant to simplify potentially complex issues, as all information could be important. Their workforces are socialized so as to notice more, explore complexity, and to check on everything.

A high-reliability culture is characterized by centralization of control, but also a degree of delegation; this balance being managed through a, "powerful system of selection, training and mutual monitoring, criticism and advice . . . [which results in] extremely efficient communications which gives the system the ability to absorb damage and surprises, and so deliver high reliability" (Bierly & Spender, 1995, p. 655). Gaba, Singer, Sinaiko, Bowen, and Ciavarelli (2003) demonstrated that safety climate was stronger in 226 squadrons of naval aviators (HROs) compared with health care workers based in 15 hospitals (nonHROs). Thus, high reliability is associated with decentralization of decision making, a no-blame orientation, effective communications, and organizational learning within the context of a superior safety culture. LaPorte and Consolini (1991) observed that during crises in HROs, decision making may be devolved to the lowest level, where relevant expertise resides. As HROs' front-line people maintain situational awareness and are committed to resilience, management is willing to defer to expertise irrespective of where it might reside in the organization (Weick et al., 1999). This can be enhanced by appropriate selection (Flin, 2001). Temporary informal networks may be used to deal with crises. Studies of HROs show that even authoritarian organizations can have the necessary degree of flexibility to maintain high safety standards, although this is by no means always the case (Hopkins, 2005).

Operating in high-hazard industries means that organizations must face uncertainty; the way in which uncertainty is managed is a key challenge for HROs (Grote, 2009). In order to function effectively as HROs, organizations require both the stability associated with minimizing risk, but simultaneously the flexibility generated by managing uncertainty (Grote, 2009, 2015; Pate-Cornell, 2012). Grote (2015) argued that HROs need to manage uncertainty in such a way that it may be reduced, maintained, and in some circumstances, increased. For example, it may be conducive for safety to provide for flexible rules, in situations where operators may choose how to work within set boundaries, or for operators to speak up and voice challenges to processes and procedures. In these circumstances, the level of uncertainty may be increased, but is necessary for effective management of risk. Grote (2015) suggested that managing uncertainty is important not only for managing unforeseen emergencies, but as a normal part of operations. How organizations achieve the right balance between stability and flexibility will differ between organizations, but will depend on how rules are specified, and how individuals and teams are sanctioned to behave. Safety culture plays a particularly important role in the management of uncertainty, as safety culture comprises shared norms and understanding of safety; therefore, safety culture will determine the norms for operating flexible rules, speaking up about safety issues, and managing risk at an individual and team level. This is also critical for the management of personal versus process safety (Grote, 2012). The relative priority given to personal over process safety was highlighted in the Texas City oil refinery accident (Hopkins, 2008), where the company was focused on reducing injuries involving personal safety (such as trips and slips) rather than monitoring indicators of process safety (such as over-pressures, release of hydrocarbons and other incidents). In the oil and gas industry, for example, there would be a gap between managing personal safety and process safety (which was not recognized in relation to the Texas City oil refinery, and was a major contributory factor in the accident). In industries where personal safety is tied to primary work tasks associated with process safety, there may be less of a gap, so that the same safety-management approach can encapsulate both personal and process safety (Grote, 2012).

10.6 Measurement approaches

A functionalist perspective tends to view culture as a route to identifying, assessing, controlling, and monitoring apparently measurable features of an organization's internal environment; in contrast, an interpretive approach seeks data from multiple sources with the prime aim of advancing learning through increased understanding, which is more of a risk identification approach (Althaus, 2005). From a functional perspective, a more quantitative or analytical approach is likely, whereas research methods adopted by taking an interpretive perspective would typically involve a narrative, phenomenological, ethnographic or a case study approach (Guldenmund, 2010). Potential ways of measuring safety culture, considering both approaches, are discussed in the following sections, organized into measures reflecting aspects of safety systems, safety attitudes and perceptions, safety behavior, or a combination of these features. The methods outlined are described in greater detail in Glendon (2006) and Guldenmund (2010).

10.6.1 Safety systems

The following three methods are among those that can be used to assess safety systems in organizations and the extent to which they are functioning effectively.

- *Documentary analysis*: This technique involves systematically reviewing a relevant sample of documents produced by an organization; for example, policies, instructions, rule books, and emergency procedures. Content analysis can be used to identify underlying themes or categories. However, documents may represent an ideal position, one to which the organization may aspire, but has not reached in reality. Therefore, this technique may be usefully combined with others to give a more holistic representation of an organization's safety culture.
- *Safety audit*: This is a methodical, planned review to determine whether a safety management system (SMS) meets its stated objectives. It critically examines all relevant system aspects to identify strengths, weaknesses, and areas of risk. Safety auditing can be a powerful tool if tailored to a particular organization or domain. Limitations of safety audits include that they can only be a snap-shot of an organization at a particular time, and are bounded by a lack of depth.
- *Systems methodology*: A systems approach could be used to study safety culture as a component of a SMS. Within this framework, three main approaches can be identified: first, a hard systems approach, which may involve event tree analysis, fault-tree analysis, or other engineering-based techniques; second, a disaster-based approach might consider an organization from a case-study perspective and seek to identify risks that it faced and how they could be addressed; third, a soft systems approach considers an organization as a cultural phenomenon, and a more ethnographic methodology would be adopted (e.g., using rich pictures; Waring, 1996). A number of ethnographic studies have been conducted examining safety culture within organizations (e.g., Atak & Kingma, 2011; Blazsin & Guldenmund, 2015; Brooks, 2008). For example, Atak and Kingma (2011) provided a detailed understanding of cultural

norms regarding the conflict between safety and production goals in an aircraft maintenance company. Brooks (2008) conducted an ethnographic study of a small wood product manufacturing company using an anthropological approach. The methodology involved two periods of fieldwork in the company separated by 8 months; during the fieldwork, informal open-ended interviews were conducted with employers and employees daily, with the researcher who was on-site up to 10 h/day over 5 days/week. This methodology can be effective in developing an understanding of the deeper levels of cultural assumptions and beliefs.

10.6.2 Safety attitudes

Self-completion questionnaires are widely used to collect data from large samples for statistical analysis. The various methodologies available for measuring workers' attitudes and perceptions include those described below:

- *Questionnaires and surveys*: Survey questions generally require answers to precoded response categories, although some may also include open-ended questions. Within organizations, surveys might use a stratified sampling approach, so that sufficient numbers of individuals from different levels are invited to participate. Well-designed surveys can provide valid and reliable quantified assessments of people's attitudes and perceptions throughout an organization. They are a quick and cost-effective means of obtaining quantified data that can attract high response rates. They may be administered online, using e-mail or a website, or in traditional paper format. However, surveys only provide a view of an organization at a particular time (cross-sectional data), although if repeated at intervals, longitudinal data can be obtained (and used to assess issues over time). Longitudinal studies often suffer from attrition effects (as the same participants fail to contribute to later stages, e.g., because they leave the organization, change department or job role, or lose interest in the study). Guldenmund (2007) argued that questionnaires can reveal little about the underlying assumptions of the safety culture and tend to reflect employees' perceptions of management.
- *Interviews and focus groups*: One-to-one interviews may range from highly structured precoded (in which an interviewer administers survey questions), through semi-structured types (including both multiple choice and open-ended answers), to purely open-ended questioning (designed to collect qualitative data in the ethnographic tradition). Focus groups are discussion-based interviews on specific topics with multiple respondents. The aim is to understand respondents' perspectives on target issues through generating and analyzing primarily qualitative data. Limitations include a restricted range of issues that can be addressed in a session. The process also depends upon the facilitator's ability to build rapport with respondents and to extract relevant information within a limited time, while keeping the discussion on track. Although generating rich data, the analysis can be very time consuming.
- *Projective techniques*: These are used to tap into people's feelings about an organization, adding an important affective dimension to the study of an organization's culture. Projective techniques are designed to reveal how respondents feel about their organization. For example, respondents might be asked to complete 20 statements that begin with the words, "This organization . . . ." Another technique might require respondents to draw a picture of their organization or to represent it through

plasticine modeling. A prime advantage of these open-ended techniques is that data are unbounded by researchers' preconceptions about how people within an organization might feel, for example, as occurs with precoded questionnaires. However, interpretation of projective technique responses can be problematic.

- *Repertory grid analysis*: This method involves identifying (typically 10–12) elements within a selected domain (in this case, an organization's safety culture), which each respondent rates on a number of constructs (typically 12–15), usually on a 5-point scale. Elements are domain components, and could include for example, senior management, middle management, first-line management, and various identifiable professional or occupational groups. Bipolar constructs are usually generated using a methodology that involves drawing three elements at random for a respondent to state how he or she thinks two are alike and differ from the third; for example, aloof–approachable, rigid–flexible, or committed–uncommitted. The grid is constructed by locating elements on one axis and constructs on the other. Dedicated software can be used to analyze the completed grid, so that results represent a particular respondent's view of relationships between parties within the organization, including their perceived similarities and differences. Aggregated responses can provide a wider view of an organization's safety culture.

10.6.3 Safety behavior

Although safety behavior is often measured using self-reports, in which respondents are asked to estimate their own behavior, more objective methodologies for evaluating behavior are also available. Measures that reflect safety behavior include those described below:

- *Observation*: Techniques range from structured observation (e.g., using standard schedules to record and observe the performance of samples of workers' behavior) to less structured ethnographic approaches. Structured observation may use some form of task analysis to break down a job into individual task elements, which can be developed into a schedule. Other techniques include behavior-based sampling (which can measure and reinforce safe working) and human reliability analysis (which can be used to identify possibilities for critical errors in complex workplace systems and make recommendations to mitigate their effects or to remove/reduce either their likelihood or potential outcome severity). Participant observation generates more qualitative data and involves one or more observers spending considerable periods of time within an organization, either overtly or covertly collecting data usually using a semi-structured approach. While structured observation can gather both accurate and rich data, it is also relatively expensive.
- *Shadowing*: This technique involves a researcher being paired with a person within an organization to observe and record relevant aspects of their work activity, ideally on the basis of a predetermined plan or representative sampling. This method can incorporate verbal protocol analysis, whereby respondents are encouraged to describe verbally the nature of their work in real time so that the researcher can understand how the work is done. While rich data can be obtained from this technique, it is labor-intensive for both researcher and respondent and relatively costly. However, relatively brief shadowing episodes can minimize these limitations.

- *Work diaries*: These involve selected organization members completing daily diaries to record critical incidents, issues, or events that are of particular importance to the area of interest, in this case safety. As events are recorded in real time, the data are likely to be more accurate than if recalled at a later date. However, the task can be quite onerous for respondents. In addition, work diaries may affect the behavior they are recording due to increased self-awareness and reflection on performance. This method may be used as an alternative to shadowing.
- *Action research*: This approach extends participant observation to involve organization members and researchers or consultants in continuing active partnership to improve selected aspects of organizational performance, such as safety. A typical action research cycle could involve planning and designing an intervention, implementing, and reviewing a program. One ethnographic approach to studying safety culture derived from participant observation is action research-based with a more systematic formulation (Glendon & Stanton, 2000). This method involves researchers and participants working alongside each other throughout a study period, so that the researchers can develop an understanding of the meaning of events and activities for participants. Daily debriefing sessions can be used to identify problems and to reflect on safety culture issues. This method has the advantage of collecting data over a period of time and providing high-quality data. However, it is a long-term investment for both organization and research team.

10.6.4 Injuries

While injury data can be problematic, where adequate data exist and can be compared with safety culture measures, this can provide useful validation for some of the techniques described above. Cooper (2000), and Richter and Koch (2004) noted that injury rate is not a simple indicator of safety culture. Adopting an interpretive approach to organizational culture that is aware of possible multiple safety cultures, Richter and Koch (2004) sought to develop a safety culture oriented toward injury prevention. They considered that a qualitative approach to safety culture that followed an interpretive approach could enhance understanding of how organizations interpret and handle risks and injuries, as well as barriers to injury prevention, arguing that such an approach is required to go beyond superficial change.

10.6.5 Triangulation

A research tradition has developed in relation to safety climate that has seen the proliferation of exclusively psychometric (e.g., questionnaire/survey) measurement approaches (Cox & Flin, 1998; Glendon & Litherland, 2001). Ojanen, Seppala, and Aaltonen (1988) argued that the only way to measure safety climate is by the use of surveys. However, these approaches have a restricted range with respect to representing measures of safety culture (see Figure 10.1). As safety culture exists at different levels and across several dimensions, it can be argued that a range of measures is required to assess it. Thus, triangulation is an important research principle, which maintains that multiple sources should be used to focus upon a particular problem or issue, ideally using both qualitative and quantitative techniques. In this way, limitations of various individual methodologies can be counterbalanced for a more robust analysis of the issues and greater generalizability of results. Forms that triangulation might take include those listed below:

- *Data*: From more than one source
- *Method*: Using more than one technique
- *Researcher*: More than one individual involved in data gathering
- *Sampling*: From more than one group within an organization
- *Time*: Collecting data on more than one occasion
- *Analysis*: Analyzing the same data in different ways

Various researchers have advocated a triangulated approach to measuring safety culture (e.g., Cox & Cheyne, 2000; Farrington-Darby, Pickup, & Wilson, 2005). Cooper (2000) proposed a methodology for changing safety culture that incorporated risk assessments, safety audits, training, surveys, and behavior change programs, while Vecchio-Sadus and Griffiths (2004) advocated a range of measures to enhance safety culture within an organization. Farrington-Darby et al. (2005) followed up a safety survey with a qualitative approach involving interviews and focus groups of railway trackside workers in which trade unions were involved at all stages and feedback of results was arranged in advance. These authors identified 40 primary factors that influenced safe behavior and safe culture, varying from immediate trackside factors (e.g., weather), through medium distance factors (e.g., supervisory style), to distal factors (e.g., contradictory rules). The organization used the research findings to institute a change program involving: risk assessment training, interactive briefings, safety critical role training, communication improvements, managing contract staff, reporting systems, and greater management commitment.

10.7 Changing toward a positive safety culture

There is little or no theoretical basis for determining what makes an organization's safety culture positive, healthy, strong, excellent, or merely good (Glendon, 2006). However, Hopkins (2005) distinguished between an absolute concept of safety culture on one hand (i.e., only organizations that have achieved a certain level of safety awareness can be said to have a safety culture), and, on the other hand, a relativistic conception (i.e., all organizations have a safety culture, but these exist on a continuum). Proponents of the former designation include Hopkins (2005) and Reason (1997). While a relativist approach permits comparisons on a spectrum, an absolutist approach requires identification of the threshold that an organization has to reach in order for it to be said to have a safety culture. The latter approach can be difficult to apply in practice as the definition of threshold level can only ever be arbitrary; whereas a relativist conception accepts that all organizations possess a safety culture, however poor many of these may be. Ultimately, this is not among the most important safety culture debates.

10.7.1 Indicators of a positive safety culture

Glendon (2006) identified a number of listings purporting to represent the characteristics of a good safety culture (see Summary Text 10.5); although these vary, they commonly emphasize the importance of senior management commitment to safety and effective communications.

The HSC (1993) suggested that organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety, and by confidence in the efficacy of preventive measures. From their review, the HSC (1993) concluded that effective health and safety provision depends as much on organizational culture as upon specific attention to health and safety matters.

SUMMARY TEXT 10.5 Features of a Positive Safety Culture

The Confederation of British Industry (1990) argued that important elements of safety culture included those listed below:

- Executive safety role for line management
- Leadership and commitment of chief executive
- Involvement of all employees
- Openness of communications
- Demonstrated care and concern for all those affected by the business

Ryan (1991) identified these four critical indicators of safety culture:

- Effective communication
- Good organizational learning
- Organizational focus upon health and safety
- Managing external factors that affect the organization's financial health

The International Civil Aviation Organization (1993) maintained that a good safety culture is one in which the following points held:

- Senior management strongly emphasize safety
- Staff understand workplace hazards
- Senior management accept criticism and are open to opposing views
- Senior management foster a climate that encourages feedback
- Communicating relevant safety information is emphasized
- Realistic and workable safety rules are promoted
- Staff are trained to understand the consequences of unsafe acts

Pidgeon (1991) argued that the three essential elements of a good safety culture were those outlined below:

1. *Norms and rules for handling hazards*: These are explicit or tacit corporate guidelines for defining what is and is not to be regarded as a significant risk
2. *Attitudes toward safety*: Individual and collective beliefs about hazards and the importance of safety, together with motivation to act on those beliefs
3. *Reflexivity on safety practice*: A search for new meanings in the face of uncertainty and ambiguity about risk

Factors identified as supporting development of a positive safety culture include management (e.g., commitment, ability, leadership, participatory style, and communication) (Cox & Cheyne, 2000; Gadd & Collins, 2002; Reason, 1997; Simard & Marchand, 1997); supervisors (e.g., lead by example, support, and participatory style) (O'Dea & Flin, 2001); individual and behavioral factors (e.g., involvement, competence, and attitudes) (Cooper, 2000); reporting systems (e.g., report near-misses, no-blame approach, feedback, and confidential); workforce involvement in risk assessment and developing best practice; rules and procedures (e.g., clear and practical); and good communications (Brown, Willis, & Prussia, 2000).

Pidgeon (1991) elaborated that effective norms and rules are not just about developing prescriptive procedures to deal with foreseeable hazards, but being alert to unforeseen hazards, and monitoring for information from a variety of sources, including outsiders and internal whistle-blowers. This openness operates at both individual and collective levels. Promoting safety attitudes depends on propagating norms and rules for handling hazards throughout an organization, and for senior managers to hold realistic views about the organization regarding hazards. Positive safety attitudes need to be developed by all members of an organization and cannot be imposed by any one group. Pidgeon also suggested that reflexivity could be developed through feedback systems, for example, incident, injury, and near-miss reporting at industry-wide as well as organizational level.

Several researchers (e.g., Grote, 2009; Weick et al., 1999) have argued that diversity and flexibility are essential to an organizational culture that contributes positively to safety. This challenges a functionalist assumption that a monolithic culture across an entire organization is desirable, and is premised upon the certainty of an unknown future in which incidents or disasters will differ from those previously experienced and also be difficult to imagine, but which could nevertheless occur. A number of authors (e.g., Reason, 1997) have caution that seeking to use components of safety culture as a defense in depth against major incidents, perhaps through a total safety culture ideal, is doomed to long-term failure through organizational complacency as well as lack of diversity and flexibility of response.

10.7.2 Safety culture interventions

Much has been written about the virtues of having a positive safety culture, but much less guidance has been issued about how organizations should go about changing toward this goal (Clarke, 2000). Culture maturity models can provide an initial diagnosis of the state of organizational safety, and identify how far an organization might be from their "ideal" safety culture, that is, the safety culture toward which they aspire (e.g., Parker et al., 2006). However, it is often difficult for organizations to plan effective safety culture interventions to move forward toward that goal. Managers are often frustrated by the failure of safety initiatives, which in their minds should have worked, and do not understand the reasons for their failure (Gillen, Kools, McCall, Sum, & Moulden, 2004). For example, a comprehensive training program was implemented by an organization in a qualitative study conducted by Gillen et al. to avoid problems with compliance. However, in the next project the same problems recurred with the training seemingly having no effect. One of the most common reasons for the failure of training programs is the lack of a positive climate for transfer of learning, including support from first-line managers. In addition, particularly when used in isolation, training will have no effect if the newly learnt procedures cannot be implemented due to inadequate equipment, resources, or supervisory commitment (Colligan & Cohen, 2004). Indeed, it could be counterproductive as it may only serve to demonstrate management's inability to provide a safe working environment and their reluctance to invest in appropriate equipment. There is also a danger in applying isolated, prepackaged safety solutions from external consultants who do not understand the particular problems faced by an industry or an organization. A quote from one of Gillen et al.'s interviewees illustrates this well, "hiring fancy consultants, especially for a small or medium sized company, to prepare a voluminous safety program [can be unsuccessful] . . . [one company] had a box full of big books, [they] set them on the table, [and said] 'This is our safety program.' [But] you look out of the window, there are guys thirty feet up in the air, no safety belt, no hard hat, leaning over. It just didn't work. It was just one of the worst things I've ever seen" (p. 238).

Dejoy (2005) described two broad approaches to achieving cultural change: a direct approach based on engaging senior managers in order to change their values and beliefs, which has a trickle-down effect; and, an indirect approach based on engaging the workforce to change their behavior, which has a bubble-up effect. Although a clear distinction between these two approaches is drawn, the main difference between them lies in the level of intervention and the techniques used to achieve change: the former focuses on attitudes, culture, and often uses ethnographic techniques, such as in-depth interviews; the latter focuses on actual behavior and uses applied behavior analysis or behavior modification techniques. Nevertheless, the aim of both approaches is changing toward a positive safety culture. This is evident, for example, in the work of Geller, one of the main proponents of a behavioral approach, who advocates behavioral techniques as a means to gaining a total safety culture (TSC) (Geller, 1994). TSC status bears every resemblance to aspects of safety culture considered earlier in this, and previous, chapters, being characterized by the features listed in the following:

- *Personal ownership of, and involvement in, safety*: Everyone feels responsible for safety and pursues it on a daily basis
- *Engagement in safety citizenship behavior*: Going beyond the call of duty to identify unsafe conditions and behaviors, and intervene to correct them
- *Supportive communications*: Safe work practices are supported via rewarding feedback from peers and managers
- *Safety is an ongoing process*: People actively care on a continuous basis for safety
- *Safety is given top priority*: Safety is not a priority that can be shifted depending on situational demands
- *An integrative approach to safety management*: Safety is a value linked with all other situational priorities

A number of barriers can affect the success of both trickle-down and bubble-up approaches to developing a safety culture. Trickle-down techniques are vulnerable to communication failures, even where there has been success in changing top managers' safety vision, due to perceptual differences between levels (Clarke, 1999). Flin (2003) reported on the use of 360° feedback and upward appraisal in one organization to identify and reduce communication failures between senior management and the workforce, where the role of middle managers in this process was emphasized. Management training can also be effective in changing corporate behavior in relation to safety compliance (Stokols, McMahan, Chiltheroe, & Wells, 2001). However, top management commitment per se is not sufficient to institute a change toward a positive safety culture. As noted by Reason (1997), not only is commitment required at the most senior level, but also competence and cognizance; that is, managers must have the requisite knowledge to apply the most appropriate solutions and also awareness of the relevant problems, described by Dejoy (2005) as the issue of right problems, right solutions. On the other hand, behavioral safety programs do not always have lasting effects on an organization, as positive effects may be difficult to sustain in the long term. In addition, behavioral programs in particular have been criticized for being control-oriented and victim blaming; the need for change may be recognized by managers as existing at workforce level only, rather than elsewhere in the organization (including their own contribution). Dejoy (2005) referred to these as problems of right messages, right people, as bubble-up approaches that depend on managers sending appropriate messages to their workforce (i.e., that they are interested in their welfare and genuinely committed to improving safety) and also effective communication of information from workforce to management. In response to drawbacks associated with both models of change, Dejoy (2005) proposed an integrated approach, focusing on multilevel problem-solving. This requires both management support and worker input, and includes both trust and effective commitment to developing a positive safety culture. The problem-solving core of this model bears resemblance to Reason's informed culture, with its emphasis on collecting and analyzing safety information.

There are a limited number of safety culture intervention studies reported and published in the academic literature. Such studies often fail to meet the most rigorous standards of design; for example, evaluation of effectiveness is based on before-after measures, rather than incorporating a formal control group. Nevertheless, safety culture interventions can provide useful information on underlying reasons for successes and identification of barriers to success. Hale, Guldenmund, van Loenhout, and Oh (2010) conducted interventions in 17 companies across different industries, including construction, manufacturing, processing, and agriculture. The authors designed a package of measures, which included the implementation of safety management systems (e.g., appointment of extra safety staff, mentors, or coaches; use of dedicated project group to develop and steer interventions; improved design of risk assessments and job safety analyses); improved procedures for collecting safety information (e.g., incident/accident/dangerous situation reporting, analysis, and follow-up action); and incentives to report incidents and dangerous situations. Successful companies, which demonstrated significant changes in safety climate, tended to implement a wider range of interventions. These companies were also supported by the company director, and had a workforce that were actively engaged and empowered by the intervention process. Training was used by both successful and unsuccessful companies, suggesting this was necessary but not sufficient to achieve change (Hale et al., 2010). A similar approach was taken by Clarke and Flitcroft (2011) in 10 companies (including seven small- and medium-sized organizations) in the construction, manufacturing, and service industries; they found that overall companies demonstrated a significant reduction in reported accidents following the intervention period, and increase in employees' perceptions of safety climate and safety participation at 12 months (which was maintained for a further 12 months). The interventions involved the implementation of training and introduction of safety systems (such as near-miss and incident reporting). A package of interventions was tailored specifically to each company's needs (as assessed through health and safety appraisal processes). The study concluded that interventions should be embedded into the company's processes and procedures, and should be integrated into the company's overall strategy (Clarke & Flitcroft, 2011).

10.8 Safety culture and risk management

An integrated risk management approach is recommended for managing human risks in organizations. This approach emphasizes systematic assessment and evaluation of risks throughout an organization, prioritizing risks and developing action plans to manage them, and implementing organizational as well as individual and group-based risk management interventions. The strength of such an approach is a focus on managerial and organizational interventions to manage risk, which recognizes the importance of all levels of management in safety (an aspect that is largely overlooked in other approaches, including behavioral and culture change perspectives). Furthermore, integrating a systematic risk management perspective with human resource management emphasizes using HR practices to enhance safety through employee commitment and involvement. Management commitment to such a system is likely to become embedded as executives see short-to-medium term bottom-line benefits of lowered costs and reduced injuries, and be further reinforced by longer-term benefits of enhanced worker relations and improved productivity.

A number of authors have devised guidelines for developing a safety culture, including Toft (1992), Wilson-Donnelly, Priest, Salas, and Burke (2005), and Glendon (2006). Key points from these publications are summarized in Summary Text 10.6. Repeated themes within these guidelines, including an emphasis on top management commitment and safety training, are also reflected in empirical evidence identifying key antecedents of a positive safety culture.

10.8.1 *Antecedents of a safety culture*

Hopkins (2005) identified sources of culture as including public pressure, disaggregation of industry bodies, and isolation of different occupational groups. Gillen et al. (2004) used focus groups of construction managers to identify antecedents of a positive safety culture; factors identified by managers included the following three factors:

1. *Management commitment to and support of safety practices*: The most successful managers were described as, "involved, proactive, principled, innovative and not afraid to take a stand" (p. 235); managers also needed to buy into safety, that is, preaching safety and meaning it.
2. *Training*: Safety training and continuing education to keep skills up-to-date; this was particularly effective within smaller firms when combined with incentives, such as lower insurance premiums.
3. *Changes in workplace culture*: Setting safety goals; decentralizing and empowering people who have a day-to-day working knowledge; and acknowledgment that work can be done safely. Failure to modify existing cultural norms (e.g., we have always done it this way) was identified as a major obstacle to establishing a positive safety culture.

Concluding that management commitment to safety had less impact on safety cultures and quality of safety activities than sometimes found in the safety climate literature, Richter and Koch (2004) suggested that macro-cultures had an important impact on the quality of safety work; for example, management networks, trade unions, professional identity, and societal regulation, which impact across organizations. Also important were internal structures and social relations, including division of labor, work content, power relations, traditions of participation, and broad commitment to safety.

10.8.2 *Safety culture as a form of risk control*

According to an anecdote from a colleague of one of the authors, it has been observed that university students who sit toward the front of a lecture theater achieve significantly better marks than do those sitting toward the back; however, high marks cannot be achieved simply by moving from the back of a lecture theater to the front. Likewise, organizations seeking to implement a set of safety practices and procedures (even though research has highlighted these practices as associated with a positive safety culture) cannot be ensured of success.

SUMMARY TEXT 10.6 Guidelines for Developing a Safety Culture

Toft (1992) argued that a holistic approach is required to change safety culture, involving the factors listed below:

- Sustained management commitment
- Sound safety policy
- Visible management support
- Allocating sufficient resources
- Using appropriate safety management techniques
- Continuous motivation of all staff
- Safety training provision
- Fostering a no-blame culture
- Organizational learning
- Persistence of purpose

Glendon (2006) suggested that, from various sources, key safety culture dimensions included those listed below:

- Extent of trust and shared concern for safety among groups within the organization
- Variety of perceptions and other aspects of culture among sub-groups
- Organizational learning, including reflection on practice and feedback systems
- Norms and rules permitting flexibility in dealing with all types of safety issues
- Top management commitment, support, and resource allocation
- Soundness of safety policy and applied safety management techniques
- Continuous motivation of all staff
- Safety training provision
- Fostering a problem solving and not a blaming approach to safety issues
- Persistence of purpose

Wilson-Donnelly et al. (2005), based on an extensive review of the safety literature pertaining to manufacturing industry, proposed the guidelines outlined below for creating a safety culture:

- Make people believe in safety: Start at the top—get a commitment from upper level management, provide feedback to employees.
- Send appropriate signals that safety matters: Communicate them clearly and precisely—effective safety policies and procedures; avoid normalization of deviance; get employees involved.
- Encourage discussion and documentation of errors: Create a climate for learning; have good information flow; and develop an error reporting system (these are the fundamentals of an informed safety culture as described by Reason, 1997).

- Search for solutions: Examine all levels and promote different methods—including existing multilevel approaches to accident investigation.
- Prepare people through training: Provide the competencies needed—including safety culture training (where the aim of the training is to create an awareness of risk taking and appropriate courses of action when a dangerous situation occurs).

Gillen et al. (2004) showed that managers who have "done the right thing" might nevertheless observe little or no effect on their safety record. However, just as a student's arrival at the front of a lecture theater must be accompanied by an increase in attention and motivation to learn, so organizations implementing safety initiatives must accompany them with changes in attitudes and beliefs throughout the organization. As Reason (1997) argued, identifying and developing essential characteristics of a safety culture through social engineering is not enough to truly have a safety culture: one can construct the elements of a safety culture, but like Frankenstein's monster, it requires a certain spark to bring it to life (Clarke, 2000). This is usually much easier said than done. Despite relative consensus with respect to factors that influence the development of a positive safety culture, conspicuous by its absence is rigorous empirical research needed to guide organizations in the practical application of such factors. In the absence of such practical advice, there is a danger that organizations' attempts to develop a safety culture may actually reinforce a cycle of failure (Pidgeon, 1998), particularly where inappropriate models are implemented to encourage organizational change (such as a traditional engineering model; Toft, 1992). Hopfl (1994) warned that management attempts to impose a corporate culture on workers can conceal discrepancies and gloss over dysfunctional aspects. Mechanisms used to develop safety culture may focus on a common rhetoric, underpinned by observable artifacts, including appropriate methods, manuals, systems, and structures, which ensure standardized behavior from workers. However, overemphasizing the external appearance of safety can lead to workers placing greater stress on consensus of behavior than the meanings upon which that behavior is based. Rather, a safety culture must imply, "some level of relationship between the corporate culture of an organization and the culture of the workplace" (Hopfl, 1994, p. 55).

While there has been a tendency among organizations to take a rather narrow view of safety interventions, there is growing evidence that at least some are taking a broader perspective. For example, interventions aimed at altering safety behavior (such as reducing violations) can be targeted at changing safety culture (Parker, West, et al., 1995). Such interventions would target the climate within which violations occur, rather than the behavior itself (e.g., strict enforcement of all rules and regulations). A safety culture that encouraged over-rigid application of rules and regulations would be likely to create a frame of reference within which behavioral consensus (compliance) is perceived as valued above appropriate (safe) conduct (Hopfl, 1994). Developing a just culture involves, "an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information, but in which they are also clear about where the line must be drawn between acceptable and unacceptable behavior" (Reason, 1997, p. 195). This approach can be reinforced by rewarding acceptable behavior and sanctioning unacceptable behavior, as opposed to a no-blame approach, where blame is not attached to actions. A safety-based intervention of this kind would be most effective as part of a broader intervention package aimed at improving worker communication throughout an organization. Neal, Griffin, and Hart (2000) suggested that interventions aimed solely at improving safety motivation (e.g., bonus and incentive schemes) are unlikely to be as effective as interventions that target both knowledge and motivation. Morrow and Crum (1998) found that safety culture was a significant predictor of work-related attitudes, including work satisfaction, job involvement, organizational commitment, and intention to stay. The authors noted that, "improved safety perceptions may have positive spill-over effects on employee-related attitudes, perceptions and behaviors" (p. 310). In a study examining the impact of safety-related variables on nonsafety outcomes, Michael, Evans, Jansen, and Haight (2005) found that workers' perceptions of management commitment to safety were positively correlated with job satisfaction and withdrawal behavior; there was also a strong positive association with affective commitment. Thus, there are potentially much wider benefits, in terms of more general job-related performance, from developing a positive safety culture than just safety-related outcomes. This acts as further evidence for integrating safety into mainstream management.

10.8.3 Risk management approach to safety

A risk management approach to safety incorporates an emphasis on strategic integration of safety with other organizational objectives and using commitment-driven HR practices to encourage worker involvement and participation. This constitutes a systematic approach to identifying and evaluating risks within an organization. A major obstacle to successful implementation of safety initiatives identified by Gillen et al. (2004) was a failure to link safety with productivity. Operating safely should be as much a part of an organization's mission as being financially successful. When safety is embedded as an organizational value, it represents an important step toward achieving a positive safety culture. Hopkins (2005) observed that "organizational cultures may be detrimental to safety, not because leaders have chosen to sacrifice safety for the sake of production, but because they have not focused their attention on safety at all . . . if leaders attend to both production and safety, the organizations they lead will exhibit a culture which potentially emphasizes both" (p. 9).

As noted earlier, a major driver of safety culture change is senior managers' commitment to safety; however, this must be accompanied by both competence and cognizance (Reason, 1997). These factors can be enhanced through an effective risk management approach to safety, such that relevant knowledge and expertise is drawn from the process of identifying, assessing, and evaluating risks. While there is no simple generic 10-point plan that can be implemented to develop a positive safety culture as a result of the risk assessment process, as illustrated in this chapter, there is a wide range of potentially effective safety interventions that would demonstrate visible management commitment to safety. Schein (1992) observed that leaders create cultures by "what they systematically pay attention to . . . this can mean anything from what they notice and comment on to what they measure, control, reward and in other ways systematically deal with" (p. 231). Change in safety culture is achieved through visible management actions showing workers that their managers care about and are concerned with safety; for example, rewards, incentives for safe performance, training, investment in safety, (Gilkey et al., 2003) and "safety management by walking around" (Luria & Morag, 2012). For further practical examples, see Summary Text 10.7.

Where management's commitment to safety is clearly demonstrated through action, this is likely to lead to more positive worker perceptions of management process. O'Toole (2002) provided preliminary evidence of a strong causal relationship between improved management commitment to safety and a significant reduction in injuries. When workers gain the impression that managers are genuinely interested in improving safety, rather than only implementing safety systems in order to appease regulators and to comply with legislation, this encourages them to trust their managers. Trust in management is an

SUMMARY TEXT 10.7 Examples of Practices to Encourage a Positive Safety Culture

Indicative practices of management commitment to safety include those listed below (Gillen et al., 2004):

- Being willing to shut down unsafe sites
- Evaluate subcontractors on safety history as well as price
- Define safety expectations for employees and subcontractors
- Uniform enforcement of safety standards for all employees
- Praising employees directly for safe performance

Examples of safety-related rewards include those listed in the following (Gillen et al., 2004):

- Bonuses or raises for safety managers tied to safety performance
- Sending employees, rather than supervisors, on safety training or to conferences
- Employee ownership of the company
- Recognition for safety ideas or suggestions

Strategies used to motivate employees include those listed in the following (Vecchio-Sadus & Griffiths, 2004):

Major strategies:

- Promote management commitment—best demonstrated by allocating resources, including time, high shop-floor visibility, participation in risk assessments and consultative committees, and by completing actions.
- Promote worker empowerment, for example, by nonadversarial labor management and an incident investigation approach that does not focus on blaming individuals.

Support activities:

- Mission statements, slogans, and logos
- Published materials (library, statistics, and newsletters)
- Media (posters, displays, audiovisual, e-mail, and Internet)
- Seminars and training (short talks and group meetings)
- Special campaigns (Health and Safety Week, health promotion, emergency response, inductions, incident reporting and investigation, risk assessment, and environment)

important intermediate variable that can significantly influence safety-related outcomes. It has been found to mediate the relationship between high-performance workplace systems and safety incidents (Zacharatos, Barling, & Iverson, 2005).

Another driver of safety culture change involves harnessing employee commitment, involvement, and participation. Vecchio-Sadus and Griffiths (2004) suggested a number of promotional techniques that could be used to raise awareness of safety initiatives among employees (see Summary Text 10.7). A number of HR practices can be used to encourage worker commitment, such as empowerment and decentralized decision making. Hofmann and Morgesen (1999) used a social exchange model to suggest that management commitment to safety encouraged return of employee loyalty through safe working behavior. O'Toole (1999) found that merely providing the opportunity and encouraging workers to participate in the safety process at eight manufacturing sites resulted in lower lost-time injuries and reduced injury-severity rates. Among seven safety factors, O'Toole (2002) found that management commitment to safety had the greatest positive perception by employees. These results suggested that worker perceptions were related to management commitment to safety, which in turn appeared to be related to injury rates. While demonstrating management commitment to safety can help to build trust between employees and managers, interpersonal trust is a two-way street: managers must also trust their employees. This can be particularly difficult initially as within poor safety climates, managers tend to view employees as responsible for injuries (and vice versa). However, as safety climate improves, views of both groups become more realistic and less polarized (Prussia, Brown, & Willis, 2003). Employing practices that encourage worker participation can serve to demonstrate that managers value employees' opinions and suggestions, as well as acknowledging employees' operational experience and expertise.

Reason (1997) discussed how reporting systems could be used to develop feelings of trust through confidentiality, indemnity against disciplinary proceedings, and separating the system from those who impose sanctions. However, this trust will be undermined in a work environment in which, for example, employees repeatedly encounter unworkable rules, managers fail to take action, supervisors put production before safety, or employees are blamed when things go wrong. Positive reinforcement of safety culture must be seen to work on a daily basis throughout an organization in everything it does, thereby encouraging establishment of new group norms and internalization of safety values. The Keil Centre (2002) noted that conducting a climate survey was often not responsible for improvements in safety culture per se, but rather that enhancement was much more closely related to changes in the work environment instituted as a result. It is also important to consider the dynamics of workgroups when instituting cultural changes. Clarke's (2006) meta-analysis of the relationship between safety climate and work injuries found the strongest relationship at group level. Thus, interventions should be considered not only from the perspective of the impact they will have upon individuals, but also the effect they will have on workgroups and intergroup relationships.

Turner and Pidgeon (1997) observed that what constituted an acceptable risk within an industrial process is continually negotiated implicitly and explicitly. Hopkins (2005) explained that worker empowerment meant that a worker could refuse to do a job that they considered to be unsafe, for which they needed adequate risk awareness training. An incident reporting system is also essential and management needs to respond appropriately to incident reports. A focus on rules, blame, and production rather than expertise could disempower employees. Risk denial also reduces the power of employees to raise safety concerns. Employees need to be empowered to make safety-related decisions. Vecchio-Sadus and Griffiths (2004) maintained that in addition to management commitment to occupational safety and strong safety management systems that are consistent with the desired culture, a key component of safety culture was worker empowerment and involvement. Kelly (1996) observed that employees were more likely to demonstrate commitment to safety if they were actively involved in decision making and problem solving and that empowerment was greater when employees were managed by principles rather than by endless rules. Worker empowerment promoted feelings of self-worth and belongingness, promoting the status of safety (Kelly, 1996).

Vecchio-Sadus and Griffiths (2004) maintained that properly managed change could result in improvements in the areas outlined below:

- *Safety culture*: Management commitment and accountability, more employees taking ownership of their work environment
- *Risk management*: More risk assessments, better job safety procedures, and other physical environment improvements
- *Overall performance*: For example, lost-time injury frequency rate, compensation claims, insurance premiums, incident investigations, and winning research contracts because of better safety culture

A number of barriers could hinder the risk-management process, primarily time, money, and resources. Investing financial resources in implementing safety initiatives is crucial. As noted by The Keil Centre (2002), the worst course of action is to raise worker expectations of change and then fail to meet them, as this highlights managers' inability to improve working conditions. However, commitment of resources in terms of personnel is also important. Safety initiatives often fail due to the lack of a champion to see them through. This is further evidence of the need to fully integrate safety into mainstream management, where safety is no longer viewed as an optional extra. Vecchio-Sadus and Griffiths (2004) described the necessity to sell safety initiatives to senior management as one of the most common challenges of health and safety professionals.

A further barrier is found in terms of embedded cultural norms and worker attitudes. Adie et al. (2005) discussed the point that safety culture is viewed primarily as a function of the organization as reflected in employees' definitions. Thus, it is essential to develop worker commitment so that employees are more willing to see the relevance of their own input and individual responsibility for safety. This is particularly important where employees are contingent (e.g., temporary or short-term contract employees). Adie et al. (2005) found that divers on offshore oil rigs (who were often short-term contract employees) were most likely to rate safety culture as having the smallest effect on risk perceptions compared with other factors, including supervisory control, worker competency, and time/financial pressure.

Rundmo (2000) found that perceived management priority of safety over production was a significant predictor of nonacceptability of rule violations, while worker acceptance of rule violations was a strong predictor of risky behavior. In organizations where safety climate was perceived to be poor, Prussia et al. (2003) found that managers believed that employees were responsible for workplace safety. They also found that similar perceptions of safety between supervisors and nonsupervisors were associated with worker perceptions of good organizational safety, and suggested that an indicator of poor safety culture was an attitude that safety was the responsibility of someone other than the employees themselves.

Describing a Royal Australian Air Force (RAAF) case study, Hopkins (2005) noted that, "attempts to enhance safety can be entirely negated by existing features of an organization's culture, and . . . these features need to be tackled directly before any real safety improvement can be achieved" (p. 81). While the RAAF had an incident reporting system, it could not identify events with harm potential. For example, there was no effective reporting system for maintenance problems. As a result of public pressure, the RAAF had greater concern for air safety than for ground safety. Other external factors affecting

RAAF culture included government cost-cutting and downsizing. RAAF cultural values included: priority of operations over logistics, a can do attitude to problems, priority of platforms over people, and command and discipline system. The F111 deseal/reseal programs relied on personal protective equipment (PPE) as the first line of defense rather than designing in engineering and administrative controls. While the RAAF recognized the hierarchy of controls in its publications, it did not put these into practice and there was no attempt to identify substitute nontoxic chemicals. This illustrated the platforms over people culture. There was also the very real threat of disciplinary action if orders were not obeyed. Normal OHS legislation did not apply to military operations on the grounds that it was believed that empowering employees to refuse to do a job that they considered unsafe could undermine the military authority system. In this case, a lack of risk awareness started at the very top (government). Hopkins (2005) argued the need to start from first principles to determine critical aspects of safety and how they can be accommodated. Even discussing risks of a job can lead to identifying means of control; that is, a risk assessment, while a degraded system is likely to pose additional risks.

It is also important not to ignore individual differences. Some individuals are more safety conscious than others and respond more readily to training. Recognizing individual differences in interventions to improve safety can help to ensure their success (see Chapter 7 for further discussion). For example, it has been noted that for interventions involving enhanced autonomy, employees who find added responsibility a burden rather than a benefit, may reject increased control.

10.9 Conclusions

This chapter has illustrated the variety found in definitions, theoretical approaches, and ways of measuring and developing safety culture. Despite attempts to draw these disparate views together, differences still exist. In terms of moving toward a positive safety culture, three approaches were identified: direct cultural change, indirect cultural change, and climate change. Each approach depends on a number of restricting factors. Direct cultural change depends on effective communication to overcome misperceptions concerning other groups, and successfully managing relationships between first-line management and workforce. Indirect cultural change depends on senior managers recognizing the need to change and being willing to enact change. Safety climate surveys depend on effective communication systems and also need management commitment and a willingness to make environmental and other changes recommended by employees. Thus, it is evident that the main drivers of change are associated with (1) demonstrating management commitment to safety and visible enactment of that commitment through instituting environmental, organizational, or work design changes, and (2) active involvement and engagement, and empowering of the workforce. An integrated risk management approach aims to systematically identify, assess, and evaluate a range of physical and psychosocial risks within an organization and to recommend a range of interventions designed to enhance safety through developing a positive safety culture.

chapter eleven

Managing risk

11.1 Introduction

The risk management (RM) framework has expanded enormously over the past 25 years, as evidenced by the number of new journals in the field presenting multidisciplinary risk-based discourses, employment of more risk professionals, enhanced application of risk-based concepts, measurements and management practices, proliferating governmental and nongovernmental participatory and enforcement agencies with their associated risk and hazard regulatory frameworks and inquiries, university units researching various aspects of risk in many OECD countries, and by public and social media content, including wide-ranging debates on an increasing range of RM topics frequently focusing on accountability and blame. The accumulation of RM and risk governance (RG) acronyms (see glossary) represent some new methodologies (or new names for revised techniques), novel concepts, and new structures or institutions developed to assist RM and RG processes. While RM and RG terminology is not addressed explicitly in this chapter, a review can be found in Waring (2013).

The various organizational, programmatic, and sociolegal phenomena reflect the risk society rubric initially popularized by Beck (1992). Ultimately, almost any and every human behavior and activity can be described and defined in terms of risk-based dialogues. It is increasingly evident that, because they impact on all aspects of our lives through institutions, organizations, communities, and jurisdictions, risk issues are also matters intimately concerned with life and living, affecting not just human societies, but also the natural environment. The World Economic Forum (WEF, 2014) report noted the trend in organizations away from individual risk planning in technical terms toward a more holistic approach to a range of less well specified risks. Of conceptual interest is the WEF's equating of "risks" as exclusively downside, perhaps also reflecting an aspect of the risk society. Contemporary risks to organizations and communities are frequently interdependent and interconnected, requiring flexible, holistic, collaborative, and resilient solutions. Chief risk officers (CROs) at the director level are often the strategic RM standard-bearers in defending organizational vulnerabilities. Designating cabinet-level national risk officers has also been proposed (Michel-Kerjan, 2012). The RM process has expanded to incorporate eight stages (WEF, 2104): (1) identify risks, (2) prioritize top risks, (3) undertake risk assessment (RA), (4) identify RM options, (5) design RM strategy, (6) design crisis management (CM) strategy, (7) implement strategy, and (8) monitor progress and update strategy.

Methods for identifying and prioritizing risks include synthesizing enterprise risk management (ERM) team findings, listing/risk matrix, reporting, interviews, auditing, workshops/meetings, research, and event-specific techniques. Deliberative strategies increasingly used by organizations in assessing risk include scenario analysis/modeling, ranking/scoring/matrices, meetings/discussion, stress test, and mapping. The ERM team plays a significant role in all aspects of the strategic RM process (WEF, 2014). Organizations' RM strategies include mitigation measures, accountability measures, supply-chain diversification, avoiding less profitable risks, risk transfer (insurance), retain risk (e.g., reserves), early warning systems, simulations/tabletop exercises, and backup sites (WEF, 2014).

CM strategies, developed to complement RM strategies, include defining roles and decision making (DM) procedures. Strategies adopted by CROs to focus attention and generate robust approaches to RM include identifying the top five risks faced by an organization and the implications of its risk appetite for managing them, assets exposed and their vulnerability, options to address these risks against current actions, and the support/resources required to address them. While learning from disasters has long been a strategic opportunity, its use has expanded within contemporary RM and RG (WEF, 2014).

The modern risk management (MRM) paradigm encapsulates a much broader perspective than the traditional and somewhat formulaic "policies and matrix" approach, in essence becoming an all-of-business model. This is consistent with Beck's (1992) assertion that risk is an inevitable concomitant of wealth production. Organizations adopting an MRM approach heed environmental conditions and the organizational context—a perspective harking back to the notion developed in the 1960s that the most successful organizations were those whose internal operations most effectively match their environmental conditions (Lawrence & Lorsch, 1969). Within a core values context, MRM incorporates an awareness of the organization's history, evaluates the internal and external environments, undertakes stakeholder assessment, and specifies the organization's goals, purpose, and intentions. More traditional RM processes include assessment, treatment, evaluation, and monitoring of risks and incorporating these processes within the regulatory framework (Jondle, Maines, Burke, & Young, 2013). Qualitative graphical representations of an all-of-business RM approach include the company dynamic response map (CDRM) developed by Arena et al. (2013).

The traditional dichotomy between natural and human-created disasters is rapidly reaching an asymptote of obsolescence. This is reflected first in the recognition of the categorization of certain risks as "na-tech," where a cocktail comprising a natural disaster (e.g., tsunami) impacts on technology (e.g., nuclear power plant) to produce a potentially deadly outcome. The interface of natural disaster and human activity is enhanced by increasing coastal urbanization through lifestyle, recreational, tourism, and trading imperatives (e.g., Genovese & Przyluski, 2013). A second representation of the breakdown of natural versus human-made disaster categories is best represented by anthropogenic climate change, which not only threatens to degrade a vast array of biological and sociotechnical systems, but could also generate further natural disasters. For example, while sea-level rise threatens multiple coastal communities with effects on social, economic, and political systems, deliberately redistributing water resources across the planet could also affect geological activity, including earthquake, and volcanic frequency and severity.

The systemic, interdependent, distributive, and potentially catastrophic nature of many contemporaneous risks has increasingly led RM to be a collaborative discourse in which, notwithstanding conflicting interests, information is freely shared for mutual benefit. Examples include public–private partnerships (PPPs). A key feature of contemporary RM is the shift toward adopting longer-term perspectives, requiring movement in organizational culture away from quarterly or annual outcomes (WEF, 2014). Internationally, G20 summits have begun to prioritize disaster risk financing and risk management (Michel-Kerjan, 2012).

Compared with previous eras, risks are increasingly (1) global (e.g., climate change, disease pandemics, financial), creating complex interdependencies, and requiring international collaboration to manage effectively; (2) intergenerational (e.g., climate change, natural resource depletion, genetic effects), such that contemporaneous events increasingly affect future generations; (3) chronic (e.g., climate change, population increase, "forced" migration)—systemic risks requiring long-term management and multilevel governance to reduce associated uncertainties; (4) catastrophic (e.g., na-tech disasters, greater variability of natural events, higher frequency and intensity of natural events), requiring more resources in disaster planning and preparedness (Kunreuther, Meyer, & Michel-Kerjan, 2013; Kunreuther & Michel-Kerjan, 2013); and (5) conflictual, requiring prioritization and trade-offs between different risks (Groso, Ouedraogo, & Mayer, 2012; Löfstedt, 2014a, 2014b; Schiller & Prpich, 2014). As neither likelihood nor impact can be measured definitively the WEF (2014) identified a major challenge as determining a common granularity for global risks, citing as problematic comparative examples a geopolitically important nation's political collapse with overall global governance failure, failure to mitigate climate change—threatening to make the earth increasingly uninhabitable, and large-scale cyber attack. The WEF's (2014) categorization of risks is summarized in Table 11.1. A starting point for tackling global risks must include long-term thinking, collaborative multistakeholder action, trust, and global governance (WEF, 2014).

The discourse of risk is about what might happen. Once something has happened, then disaster management becomes preeminent. Some risks are almost impossible to study (e.g., to civilians located within war zones). Others are effectively out of range due to relevant information being classified (e.g., national security threats), while others are very difficult to study because of the resources required, perhaps involving considerable travel, lengthy study periods, or large numbers of researchers (e.g., cross-cultural phenomena that can only be studied longitudinally). Being absented from violence-inducing ideologies or extreme circumstances that confront a substantial proportion of the world's population, including poor sanitation, absence of potable water, famine, war, disease, and everyday personal violence, risk researchers, and other experts may resort to reporting on relatively obscure or purely conceptual aspects of risk. Risk researchers, almost exclusively from Western stable democracies and who are free to publish, are largely exempt from experiencing and researching the most prevalent risks confronting a large proportion of the world's population. We have the luxury and the security of developing grand (and not-so-grand) theories and undertaking ever more sophisticated research using clever methodologies and advanced statistical analyses. The relevance of our theories and research for a majority of the world's population remains at best highly problematic and at worst largely irrelevant. While no one could deny that people in advanced economics die and are injured or made ill as a result of many of the risks that they face, their injury, disease, and fatality incidence rates are significantly lower—and their mean lifespans correspondingly longer and mostly healthier—than populations in most other countries.

Risk researchers conduct the research they are allowed to do by the political context within which they operate. Such a context tends to generate self-censorship and opportunism in selecting research topics and agency funding. For example, in the United States the powerful gun lobby's political agenda and extensive influence effectively precludes researchers from studying risks associated with gun ownership, leading risk researchers to study topics that are accessible and for which they can obtain funding. Despite these often self-imposed limitations, researchers have accessed a wide range of risk-generating events and situations, all of which require some form of RM. A contemporary RM feature is the extensive range and varied nature of risks studied, which to some extent reflects the way in which risks and their management have been defined, and how this range continues to be extended. While some RM implications derived from published individual studies appear either obvious or too general to be helpful, they can be accepted as part of

Table 11.1 Global Risks

Category	Risk
Economic	Financial crises in key economies
	Major financial mechanism or institution fails
	Liquidity crises
	Structurally high unemployment/underemployment
	Oil-price shock to global economy
	Failure/shortfall of critical infrastructure
	Decline of importance of U.S. dollar as major currency
Environmental	Greater incidence of extreme weather events (e.g., droughts, storms)
	Greater incidence of natural catastrophes (e.g., tsunamis, floods)
	Greater incidence of human-induced catastrophes (e.g., oil spills, nuclear accidents)
	Major biodiversity loss and ecosystem collapse (land, marine)
	Water crises
	Climate change mitigation and adaptation failure
Geopolitical	Global governance failure
	Political collapse of a nation of geopolitical importance
	Increasing corruption
	Major escalation in organized crime and illicit trade
	Large-scale terrorist attacks
	Deployment of weapons of mass destruction
	Violent interstate conflict with regional consequences
	Escalation of economic and resource nationalization
Societal	Food crises
	Pandemic outbreaks
	Unmanageable burden of chronic disease (e.g., diabetes, obesity)
	Severe income disparity
	Antibiotic-resistant bacteria
	Mismanaged urbanization (e.g., planning failures, inadequate infrastructure)
	Profound political and social instability
Technological	Breakdown of critical information infrastructure and networks
	Escalation in large-scale cyber attacks
	Massive incident of data fraud/theft

Source: World Economic Forum. *Global Risks 2104: Insight Report*, 9th edition, World Economic Forum, Geneva, Switzerland, 2014.

a broader context of accumulating knowledge across a wide spectrum of risks, as well as the detailed models and data supplied by the authors.

One way of examining the contemporary RM landscape is to review recently published topics and methodologies. It would be impossible to review more than a relatively small proportion of the literature in this burgeoning field. The ISI Web of Science reported the number of journal papers on risk perception and risk communication (RC) topics alone in the 25 years between 1989 and 2013 to be approximately 7000 (Bostrom, 2015). The total number of publications on all aspects of risk is many times this figure. For this analysis, recent issues of *Journal of Risk Research* (*JRR*), and *Risk Management:*

A Journal of Risk, Crisis and Disaster (formerly *Risk Management: An International Journal*) were reviewed. These journals were selected to reflect a global perspective on risk and RM issues, as well as reflecting a wide range of risk issues authored by researchers from 47 countries. *JRR* in particular has been a key repository of current research, conceptual thinking, and documented contemporary RM practice and development. Arguably, this journal is the prime forum in which the most general level of contemporaneous scientific debate has been conducted on risk related concepts that have RM implications. The dataset comprised selected papers published in these journals 2011/12–2014/15. This chapter was prepared in parallel with another chapter by the first author with the papers reviewed in the current chapter being those most aligned with the WEF (2014) categorization of risk, and the remaining papers reviewed in Glendon (2015).

Table 11.2 shows the relative contributions of authors from the countries represented in this section of the risk management literature in three ways. The first column after the country name shows the total number of papers with at least one author from that country. On this ranking, the United Kingdom is followed by the United States, then the Netherlands, Germany, Norway, Italy, Sweden, France, Australia, Canada, and Switzerland. An alternative picture is to represent the relative contributions of authors from different countries, which is done here by dividing the score of unity for each paper by the number of authors and assigning the resultant scores to the author's country as designated on the paper. This exercise produced an almost identical overall ranking (middle column). The right-hand column is the Collaboration Index (CI), which is one minus the country contribution score divided by the total number of papers with one or more authors from that country. The higher the CI, the greater the degree of collaboration of authors from that country with authors from other countries generating scientific papers on risk issues in these two journals. While the CI has little meaning when considering the relatively small contributions from countries in the lower half of the table, it produces a rather different ranking for the countries in the upper part of the table. For countries whose authors contributed at least six papers, it shows Turkey to have the highest CI, followed by Germany, Finland, the Netherlands, Ireland, Italy, Norway, Spain, and the United Kingdom. Of this group, the United States has the second lowest CI score, with India at zero (i.e., no collaborative papers). A feature to note from this quantitative exercise is that while the distribution is heavily skewed toward OECD countries, the authors contributing to the RM debates extend well beyond this group of countries.

As far as is feasible, the key elements from this review of selected risk literature will be incorporated within the five macrolevel risk headings used by the World Economic Forum (WEF, 2014): economic, environmental, geopolitical, societal, and technological risks. However, using the WEF's definitions and coverage of these major risk categories still leaves some risks outside the WEF framework, meaning that other categories will be needed to classify the risk literature reviewed. These are reviewed in the companion chapter (Glendon, 2015). One critical distinction between the WEF approach to risks and that of published risk researchers is that the WEF review covers 31 major risks within its five macrolevel categories and a key aspect is its emphasis on the interconnectedness of global risks. At the center of its web of interconnected risks are the "big six": global governance failure, climate change, fiscal crises, income disparity, unemployment/underemployment, and political/social instability. The WEF report noted that "The risk of climate change by far displays the strongest linkages and can be seen to be both a key economic risk in itself and a multiplier of other risks, such as extreme weather events and water and food crises" (p. 21). Most of the other major risks are linked to one or more of the central six. Just beyond, are a further 11 risks: extreme weather events, water crises, food

Table 11.2 Contributions from Researchers in 47 Countries to Risk Management Papers in Two Journals 2011/2012–2014/2015

Country	No. authored papers	Country contribution	Collaboration Index
United Kingdom	67	52.96	0.21
United States	57	52.30	0.08
The Netherlands	31	23.07	0.26
Germany	31	21.52	0.31
Norway	21	16.43	0.22
Italy	21	16.10	0.23
Sweden	20	17.27	0.14
France	18	15.16	0.16
Australia	16	13.42	0.16
Canada	16	13.19	0.18
Switzerland	16	13.30	0.17
China	13	11.43	0.12
Belgium	10	8.83	0.12
Japan	9	8.00	0.11
India	8	8.00	0.00
Spain	8	6.25	0.22
Finland	8	5.62	0.30
South Korea	7	6.00	0.14
Ireland	6	4.55	0.24
Turkey	6	3.44	0.43
Serbia	4	3.13	0.22
Malaysia	4	3.00	0.25
Denmark	4	2.75	0.31
Greece	3	3.00	0.00
Israel	3	3.00	0.00
Taiwan	3	3.00	0.00
New Zealand	3	2.33	0.22
Tunisia	3	2.20	0.27
Brazil	3	2.17	0.28
Iran	3	1.84	0.39
Czech Republic	3	1.47	0.51
Portugal	2	1.50	0.25
Singapore	2	1.50	0.25
South Africa	2	1.50	0.25
Austria	2	1.33	0.33
Hong Kong	2	1.33	0.33
Ethiopia	2	1.25	0.37
Poland	2	0.77	0.61
Chile	1	1.00	0.00
Estonia	1	1.00	0.00
Mexico	1	1.00	0.00

(*Continued*)

Table 11.2 (Continued) Contributions from Researchers in 47 Countries to Risk Management Papers in Two Journals 2011/2012–2014/2015

Country	No. authored papers	Country contribution	Collaboration Index
Slovenia	1	1.00	0.00
Kazakhstan	1	0.50	0.50
Slovakia	1	0.50	0.50
Jordan	1	0.33	0.67
Zimbabwe	1	0.33	0.67
Hungary	1	0.20	0.80

crises, interstate conflict, state collapse, liquidity crises, financial mechanisms/institution failures, corruption, terrorist attacks, cyber attacks, and critical information infrastructure breakdown. Where RM solutions or suggestions are provided by the authors, these are indicated.

11.2 Economic risks

As most of the debate on economic risks is conducted in specialist journals it was unsurprising that the selected journals published a relatively small number of papers under this WEF heading. Of the nine papers specifically addressing economic or financial issues, most adopted an insurance-based thematic. Methodologies used to address this topic included case study, documentary, database, and legal case analysis, surveys, interviews, observation, workshops, and experimental approaches. Describing a context characterized by DM, global industrial investment risk and associated theories, manufacturing globalization, threats, and opportunities, Kumar and Gregory (2013) described RM's multidisciplinary history since the mid-seventeenth century. To determine fault and negligence, Faure (2014) noted the need to identify the "ideal combination" of regulation, liability rules, and insurance. From a risk regulation (RR) perspective Baram (2014) reviewed the influence of liability law and insurance on the safety management of industrial operations and products, particularly in cases of major accidents, observing that greater RR flexibility created new uncertainties. Considering liability and "soft law" regulation for nanotechnology within a context of ISO and other standard-setting bodies, Marchant (2014) identified liability and insurance as key drivers that encouraged companies to participate in voluntary RM programs for nanomaterials. Considering risk insurance from a political perspective and using a grounded theory methodology, Baublyte, Mullins, and Garvey (2012) identified the key elements to be the underwriting criteria: tacit knowledge, trust, intuition, and heuristics.

Credit RM, bounded rationality and subjective expected utility provided the theoretical framework for Ranyard and McHugh (2012) to report that consumers' DM on payment protection insurance, and willingness to pay (WTP) were relatively insensitive to changes in level of cover. Game theory modeling with cooperative and noncooperative solutions provided the basis for Ayuso, Bermúdez, and Santolino (2012) to explore motor insurance claims, revealing that because claimants were averse to risk and confrontation, as well as being pessimistic about trial outcomes, 95% of cases were settled by negotiation. Using a risk-as-feelings paradigm to explore financial risk tolerance, Lucarelli, Uberti, and Brighetti (2015) studied risk perception (RP), DM, investment behavior, and emotion recognition with an Iowa gambling task (IGT) methodology. They found that some people subjectively declaring themselves to be risk averse before the IGT task were risk takers and vice versa. The authors concluded that because emotions influenced risk-tolerance forecasting, physiological arousal was a much better predictor than self-report for estimating risk tolerance. Sawalha, Anchor, and Meaton (2012) studied the banking sector in Jordan, considering threats to business continuity and disaster recovery. A business continuity management (BCM) framework led these authors to reinforce the importance of cultural background as a significant influence on BCM practices.

11.3 Environmental risks

11.3.1 Greater incidence of extreme weather events

Using a field experiment with cross-sample differences between Chinese media/advertising freelancers and farmers to explore risk attitudes (e.g., risk aversion, RP) about disaster insurance, Ye and Wang (2013) found that lower income households and more educated people were more risk averse, advocating targeting insurance to income groups. They found that accurate RP for disaster risks was unrelated to willingness-to-pay (WTP) for disaster insurance (Ye & Wang, 2013). Using damage function analysis, scenarios, and database interrogation with the sea, lake, and overland surge from hurricanes (SLOSH) computer model, geographic information system (GIS), and maximum envelope of water (MEOW) methodology, Genovese and Green (2015) studied the projected economic impact of hurricanes and generic climate change (CC) in the highly urbanized coastal SE Florida region. They calculated very high losses (billions of dollars) in the absence of protections. Solution adaptation strategies for different protection heights could be estimated using RA and RM models (Genovese & Green, 2015). Adopting a thought experiment based on simple damage modeling scenarios involving hypothetical "tropical cyclone steering technology," Klima and Morgan (2012) concluded that DM complexities made it undesirable to modify the direction of a tropical cyclone. Using a combined CM, RG, and RA framework to assess vulnerability to coastal flooding, emergency response planning, windstorm, and storm surge cases, Genovese and Przyluski (2013) revealed that lack of knowledge led to poor anticipation of flood and had a negative effect on warnings. Urbanization drastically increased exposure, while poor national/local RM agency coordination was revealed. RM solutions included assessing local DM needs to integrate risk, and moving from post-disaster response to anticipatory mode (Genovese & Przyluski, 2013). Using interviews to generate personal ratings from a sample of those exposed to U.S. Superstorm Sandy, Burger and Gochfeld (2015) obtained data on RP, hurricanes in general, concerns (e.g., property damage, H&S, inconvenience, ecological services), and stress. The study provided input for future preparedness plans, improved resilience for severe weather events, and reduced public health risk (Burger & Gochfeld, 2015).

11.3.2 Greater incidence of natural catastrophes

Focusing on political risk communication (RC) in a forest fire disaster, within a constructionist framework Gesser-Edelsburg and Zemach (2012) reported that unless it was part of policy to change priorities to benefit the population, "cover-up" RC was publicly perceived as a cover-up failure. The recommended RM solution included creating a clear communication continuum to ensure stakeholder inclusion, providing a common narrative addressing public values and norms, and building trust in political leaders (Gesser-Edelsburg & Zemach, 2012). A wildfire risk forecasting case study from a knowledge society perspective assessing meteorological data and patrolling, identified an RM solution being aided by full knowledge from articulation between technological and other knowledge sources (tacit, practical, "profane") to address the fragmented knowledge problem (Bruzzone, 2015).

Different countries face varying combinations of natural disaster risks. Surveying socio-cultural influences on worry in a Norwegian sample to such events as rockslides and tsunamis, Rød, Botan, and Holen (2012) identified seven determinants of worry. Those who trusted experts and talked more with them also worried more. An RM solution included using multiple approaches when using RC to address public worries, including a focus on community assets (Rød et al., 2012). Risk zones in the greater Lisbon region of Portugal were identified by analyzing 38 variables involving earthquake, flood, flash flood, landslides, tsunami, and coastal erosion risks (Guillard-Gonçalves, Cutter, Emrich, & Zêzere, 2015). From census data, the authors developed a social vulnerability index (SoVI), susceptibility maps, and a vulnerability × susceptibility matrix. The analysis could identify exposed populations and determine their relative risk (Guillard-Gonçalves et al., 2015). Considering earthquakes as one of a number of possible natural disasters (also floods, avalanches, forest fires, landslides, earthquakes, windstorm), Beck, André-Poyard, Davoine, Chardonnel, and Lutoff (2012) developed a SoVI from a household travel survey, creating spatial and temporal maps to identify community vulnerabilities. These authors recommended targeting preventive information on districts and groups (Beck et al., 2012). An emergency events database analysis of five hazard types to consider multiple hazard events was the basis for a study by Orencio and Fujii (2014). Reviewing geophysical (GIS), meteorological, hydrological, climatological, and biological contributions to natural hazards, disaster risk in the Philippines, the authors used multihazard RA and a risk matrix to identify overall disaster risk potential with hazard components: area covered, frequency, duration, affected population, and damage cost. They concluded that multirisk assessment can aid DM for disaster prevention and planning (Orencio & Fujii, 2014).

Using Hurricane Katrina as a case study to identify factors affecting emergency evacuation compliance, Kim and Oh (2015) surveyed the local community to gather data on disaster response and policy compliance, as well as personal knowledge and experience. The authors determined that enhancing disaster management policy effectiveness required a new focus on institutional capacity and process. Greater public knowledge and trust in government increased compliance with evacuation orders (Kim & Oh, 2015). Comparing individual differences (IDs) in a German sample of survivor groups, Knuth et al. (2015) found that emergency experience of small- and large-scale events increased RP, while gender and age moderated risk accuracy estimates.

Using a case study, science and technology studies, and focus group methodology within a constructivist paradigm to assess emergency planning, Rossignol, Turcanu, Fallon, and Zwetkoff (2015) assessed vulnerability within a cultural factor and resilience context. The authors noted that stakeholder participation could inform vulnerability analysis in emergency planning and aid learning (Rossignol et al., 2015). Also adopting a focus group methodology as well as text messaging, McGee and Gow (2012) studied emergency alert tornado and fire threat warnings on Canadian campuses. Considering warning perception, comprehension, belief, and DM within an action framework, the authors revealed off-campus evacuation to be problematic, with relevant variables including uncertainty about nonspecific threats and where to evacuate. The message needed to be from a credible source, with most respondents reporting that they would seek to verify the message (McGee & Gow, 2012). Scenarios in which end-user evaluation feedback on a fire emergency was used to develop a human–computer interaction/interface for emergency first response operations, were employed by Prasanna, Yang, and King (2013) as part of a goal directed information analysis. Identifying eight situation awareness (SA) "demons," when developing the software prototype and information system support (DM, alarms, interfaces), the authors' system design took account of: information overload, stressors, attention tunneling, misplaced salience, system complexities, out-of-the-loop syndrome, limited working memory, and inappropriate mental models (Prasanna et al., 2013).

A field study using focus group and expert data from nine countries to study emergency evacuation, security, and survivor behaviors, while revealing cross-cultural emergency event types, identified four generic stages: beginning, realization, evacuation, and aftermath (Knuth et al., 2014). An experimental Chinese study using expectation maximization models, decision theory, and power distance as theoretical frameworks addressed cultural differences in DM, framing effect, expected value, reflection effect, and eye movements in emergency planning (Sun, Rao, Zhou, & Li, 2014). The researchers discovered a gap between formulating and implementing emergency plans. Governments' framing (e.g., on health issues) differed from that of individuals, with the former taking a broader view, while project managers made "one-shot" decisions (Sun et al., 2014).

Studies from Australia, Chile, China, and Japan addressed earthquake disasters. By randomly assigning surveys to earthquake affected groups to elucidate the effect of message source (publicity, w-o-m) and ambiguity tolerance (AT) on RP and earthquake insurance purchase intent, Zhu, Xie and Xie (2012) found that while RP was a mediator, AT moderated the effect of message on purchase intent. A case study of Puerto Aysen in Chile used documentary analyses and stakeholder interviews to identify personal anxiety, over-reaction, and lack of control, along with contradictory scientific reports, lack of seismic culture, media role, inadequate RC, and low participation as contributing to a sociopolitical DM crisis (Soule, 2012). From a social construction of risk framework within the sociological and organizational tradition, Soule (2012) identified rejection of technocratic and centralized RM, as well as local dissatisfaction with information and DM processes as barriers to effective RM strategies. Adopting a flowchart methodology to consider risk mitigation through performance-based design and safety guaranteed time target in the context of post-earthquake fires in urban buildings, Behnam, Skitmore, and Ronagh (2015) noted that buildings required RA both for seismic vulnerability and for post-earthquake fire vulnerability.

In a rare longitudinal survey in which Japanese respondents ranked 51 risks, Nakayachi, Yokoyama, and Oki (2015) combined the availability heuristic and finite-pool-of-worry hypothesis to account for post-Fukushima public anxiety change in terms of hazard type risk ranking. Overall, post-Fukushima anxiety levels declined. However, while major recent hazards experienced (nuclear accident, earthquake, national pension plan failure) were ranked significantly higher, many others were ranked significantly lower. The authors concluded that as a result of recent experience, from a global perspective, publics may support irrational (e.g., on CC) RM choices (Nakayachi et al., 2015).

Fukushima was a prime example of a na-tech disaster, in which a natural disaster interacts with a technological hazard to magnify and diversify the impact of the initial event. Considering natural hazards as an external risk source for chemical facilities, Krausmann and Baranzini (2012) sampled 14/27 EU states to recommend guidance on na-tech RA as a high priority for risk reduction of the impact of natural hazards on industrial installations. Using multiattribute value theory, multicriteria decision analysis, DM trial, and evaluation laboratory methods to assess vulnerability (fragility, resilience, exposure) to an industrial disaster; Merz, Hiete, Comes, and Schultmann's (2013) case studies with sensitivity analysis derived a composite indicator (regionalization method). Using vulnerability mapping and GIS software to produce exceedance probability flowcharts to understand process industry accidents caused by volcanic ash, Ancione, Salzano, Maschio, and Milazzo (2015) developed tools to save time and simplify work for local authorities and planners confronted by volcanic na-tech events.

Finally, under this subheading is considered disaster management, relief, and recovery. Using the Malaysian National Directive regulatory framework to consider inter alia, regulatory compliance, responsibility, recovery, skills, information, housing, and disaster victims, Roosli and O'Keefe (2011) considered that the disaster management training shortfall needed to be addressed and other barriers to effective implementation also removed. Incentives were required to engage relevant actors (Roosli & O'Keefe, 2011). Reviewing the Chinese government-business nexus, corruption, venality, tense social contradictions, strong government-weak society, violent conflict, economic development priority, and a policy agenda that promoted unitary responsiveness (U-form) to natural disasters, Luo (2014) detailed the effects of this political structure on emergency response levels. The author's political power concentration social analysis based on centralism principles also pointed to increasing social inequality, human rights violations, promotional tournament model, and government-induced disasters, with disaster relief accorded low priority. While response to sudden disasters (e.g., earthquakes) was good, response to human-induced chronic disasters (e.g., SARS) was poor. Control of environmental hazards, epidemic transmission, food safety, mass disturbance, and other human-induced disasters would depend on China's transition from U-form to multiple (M-form) responsiveness (Luo, 2014). From hurricane Katrina survivor panel survey data, Kim and Oh (2014) found that as well as government performance in initial disaster recovery, individual perceptions of future lives, along with race, risk, and property damage, were important in evacuees' decisions of whether to stay in their predisaster community. Effective RC was a key RM component (Kim & Oh, 2014).

11.3.3 Greater incidence of human-induced catastrophes

For a gas pipeline case, considering warnings, safety, reporting culture, and expertise within hazardous industry settings as for high reliability organizations (HROs), Maslen (2015) deemed it important to learn from near misses and small failures. Organizational learning requires a combination of methods, including rules and procedures (Maslen, 2015). Adopting a RG and responsibility attribution framework to assess fire safety legislation for hotels in Sweden, Larsson, Grunnesjö, and Bergström (2012) identified ambiguity and unclear political goals as stumbling blocks. An ethnographic methodology including stakeholder analysis, interviews, and a rich picture resulted in the notion that post-fire conviction was ethically problematic due to different stakeholders' definitions of "reasonable extent" (Larsson et al., 2012). Describing a case study of a smouldering closed-space fire in an underground coal storage facility, with autoignition as an emerging risk,* as RM analysis components Sipilä, Auerkari, Heikkilä, and Krause (2013) considered fire detection, monitoring, prevention, control, and extinguishing methods, before concluding that action for early detection and mitigation was required. In a parallel underground coal storage case using event chain analysis, this time involving freezing as an emergent

* This should probably read "emergent risk." "Emerging risks" may be identified as novel risks with unknown harm potential, which may be difficult to study with conventional RM tools, and may interact with other risks. Emergent risks arise as unexpected effects from other processes—for example, synergistic or unforeseen effects of chemicals on the environment or human body.

risk, Sipilä, Auerkari, Malmén, et al. (2013) advocated preparedness for rare or unforeseen events as key to a risk mitigation strategy. Experimentally manipulating trust and liking as mediators to study RC effectiveness, with uncertainty, self-efficacy, and behavior as other variables, de Bruin, Stone, Gibson, Fischbeck, and Shoraka (2013) considered unexploded ordnance. Addressing RC goals associated with specific risk understanding, affective response, and DM, it was concluded that graph-with-text display should be used with low-numerate people. High-numerate people liked the text-only display. To display uncertainty, they recommended using graph-with-text (de Bruin et al., 2013).

Considering vulnerability reduction measures, land use planning, costs and benefits, as societal risk components in a series of hazardous substances cases, Neuvel, de Boer, and Rodenhuis (2015) identified key factors in implementation failures as lack of clear policy objectives, intergovernmental and intragovernmental values and interests, communication and coordination problems between actors, administrative control limits, and the capacity of those involved. Hazardous sites with major accident potential case study analyses (Toulouse, Buncefield + 3 atypical accidents) were described by Paltrinieri, Dechy, Salzano, Wardman, and Cozzani (2013). Using various conceptual frameworks, including the "Swiss cheese" model, hazard identification (HAZID), traditional RA, the iNTeg-Risk framework, accident analysis, risk appraisal failures, and bow-tie analysis, the authors identified low RP of emerging risks related to atypical accidents, combined with lack of knowledge about related events (e.g., early warnings), and many common failures, meant that new techniques were required (Paltrinieri et al., 2013).

Reviewing a hazardous facility siting case involving landfill expansion, risk sensitivity, threat, RG, RP, risk amplification, risk sensitization, fairness, ripple effect, threat, and NIMBY, Larock and Baxter (2013) used a number of conceptual frameworks, including cultural theory of risk, psychometric paradigm (with RP dimensions dread, etc.), social amplification of risk framework (SARF), risk society, and political process. The authors concluded that risk-hazard controversies can foster risk-averse locations or communities that extend to other site risks (nuclear, chemical, incinerators) when new hazard sites are proposed. Reviewing workshop expert assessments of previous cascade failures in 17 critical infrastructure subsectors, Prezelj and Žiberna (2013) considered network-based risk, extreme events, worst case scenarios, CM, cross-sectoral incidents, complexity, and unpredictability. Using a network-based RA framework with time, consequence and interdependency variables to create matrices, the authors identified the riskiest subsectors as those on which other subsectors directly and heavily depended, these being electricity, ICT, road transport, and financial instruments. It was concluded that RM should focus on infrastructures with the greatest network-based risk, this being a better measure than direct risk (Prezelj & Žiberna, 2013).

Risks arising from the chemical and petrochemical sectors provided the context for a number of papers, several using the European Commission's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) framework following Löfstedt's (2014a) initial contribution. The REACH four-way categorization classifies risks as either simple, complex, uncertain, or ambiguous (Devilee, Verhoeven, Beekman, & Knol, 2015). Löfstedt's (2014a) three case studies, involving interviews with 90 EU policy makers, considered the substitution principle, regulation, the precautionary principle (PP), chemical control policy, risk–risk trade-offs, RA, and RM, as well as risk transparency, consistency, and predictability. Concluding that the substitution principle was a blunt and imprecise regulatory instrument to be used with care on a case-by-case basis, the author argued for chemical regulation to be rooted in evidence-based policy-making (Löfstedt, 2014a). Seeking harmonization on the basis of RA and RR, Öberg (2014) urged impact-based substitution, while on the basis of acceptable risk, RA, risk trade-off, and the PP, Aven (2014) argued for a lower level of risk. That RA may be problematic for hazard categorization, led A. Olofsson (2014) to note that the substitution principle was influenced by underlying conflicts between different interests and viewpoints. Considering value judgments about costs and risks, Renn (2014) observed that while substitution could work if there were no disbenefits, it might replace one hazard with another, as well as increase uncertainty, massively increase costs, and jeopardize competitiveness. Good business practice was highlighted by Girling (2014), who argued for DM to be based on sound science and full RA, with a risk-based approach used to make exposure comparisons.

In considering public attitudes and information overload, the Royal Society of Chemistry (2014) opined that "hazardous substance" was a misleading term, and that RA should be used to aggregate individual hazards. This position was echoed by Dudley (2014), who discussed hazard versus risk-based substitution and RR, as well as diverse public values and preferences. As predicting the outcome of an intervention was problematic, the author advocated risk–benefit analysis. Considerations included usage, people disagreeing on what constituted societal improvements, while RA tells what is, not what should be, which is unhelpful for policy DM (Dudley, 2014). Pointing to the expense of risk–risk analysis and that precaution, common law liability, and protective goals also required consideration, Abelkop and Graham (2014) noted that substitution was only one of a number of tools for managing chemical risk, and should be seen as a guideline rather than a policy tool. Industry not government should prove safety. Various RA measures could be used to create incentives for continuous safety improvements, including green chemistry (Abelkop & Graham, 2014). After studying seven cases using socio-economic analysis, RG, and RA, Devilee et al. (2015) concluded that the REACH restriction process would benefit from preassessment to characterize risk type for designing evaluations.

Social constructionism provided the framework for a case study on flame retardant compounds. Data gathering included observations in technical meetings, and stakeholder interviews, with risk transformations and risk trade-offs being considered through qualitative template analysis (Busby, Alcock, & MacGillivray, 2012). The authors argued that risk transformations may be seen as either emergent/accidental or deliberate by some actors, or may be seen within the context of commitment to a particular technology (e.g., chemicals as flame retardants). Stakeholder analysis provided the framework for a study of integrated testing strategies (ITS), chemical assessment, and toxicological testing (Gabbert & Benighaus, 2012). From thematic analysis of interview data, the authors identified divergent stakeholder views on ITS limitations and acceptance, before urging greater stakeholder integration and dialogue (Gabbert & Benighaus, 2012). The petroleum industry provided the context for Kringen (2014) to employ a number of systemic models to address issues relating to liability, regulation, blaming versus nonblaming approaches, causal attribution, and underlying root causes. The author highlighted contradictions between legal liability (punishment & retribution) and RM (learning) approaches to industrial failures, noting that regulators can mediate between judiciary and RM contexts (Kringen, 2014). Also from the Norwegian petrochemical sector, using root cause analysis to interrogate an investigation reports database, Vinnem (2015) reviewed the catastrophe potential for major accidents (e.g., Piper Alpha), from hydrocarbon leaks, and the role of compliance, noting that many failures did not have multiple operational barriers (e.g., verification & leak test), and that it was critical to perform tests independently and according to procedures. Verification failures might arise from work practice errors, noncompliance with documents, not conducting RA, and change management failures (Vinnem, 2015).

A reflexive critique on the politics of risk ("creating consent") in the petrochemical sector by Saiita (2012) argued for considering alternative developments in the light of communities' frequent ambivalence about risks. The iNTeg-Risk framework was used for Bayesian inference in the 2005 BP Texas City refinery case study (Paltrinieri, Khan, & Cozzani, 2015). Combining HAZID, dynamic RA and RM techniques, DM, early warning, experience, and safety culture, the authors argued that an innovative dynamic RA method coupled with advanced HAZID technique could have predicted the BP incident (Paltrinieri et al., 2015). A range of hazardous materials substances featured in an Israeli hazardous plants mapping exercise, which included petrochemical, chemical, cold storage, heavy metal, power stations, pesticide factories and warehouses, and hazardous material plants (Blumenfeld, 2013). The author identified potential future problems from hazardous sites located close to population centers, transportation arteries, and water sources, urging the development of a geo-tool for DM in the face of terrorist activity, and earthquake risks (Blumenfeld, 2013).

From a database of environmental accident litigations from hazardous operations, a legal cases analysis prompted Bentata (2014) to address RR, informational transfers, and legal system dynamics—liability, insurance, and regulation. The author noted the complementarity of civil liability and regulation, with each promoting a duty of care in different ways to promote smart interdependencies that mitigated civil liability and regulatory failures (Bentata, 2014). Mental maps, RP, and GIS formed the framework for a mixed methods (focus groups, survey) French study of landscape and industrial, risk sensitivity, and worry (Bonnet, Amalric, Chevé, & Travers, 2012). The authors identified physical attributes of industrial landscape (chimneys, flare stacks, buildings, etc.) as prime determinants of risk sensitivity (Bonnet et al., 2012).

Addressing more psychological features of the petrochemical industry, Tortosa-Edo, López-Navarro, and Llorens-Monzonís (2015) used the value-belief norm hierarchical model in which values affect beliefs, then attitudes, and then behaviors, to review legislation, negative affect, trust, need for information, and risk information asymmetry within a community. Viewing RC as a long-term process involving active dialogue with stakeholders, the authors argued for basing RC policy on personal environmental beliefs (Tortosa-Edo et al., 2015). Considering regulation within the context of EU Directive 1107/2009 on pesticides, Hunka, Meli, Palmqvist, Thorbek, and Forbes (2015) reviewed protection goals for environmental risk assessment (ERA), RC, EU policy change, advocacy coalition framework, uncertainties, and increased complexity. Noting the slow uptake of scientific developments into ERAs and protection goals, the authors explained how different stakeholders (researchers, regulators, industry, farmers) had distinct worries and priorities (Hunka et al., 2015).

The offshore oil and gas industry was the context for Tveiten and Schiefloe's (2014) study of RA, sense-making, and paradigm change. Interviews, observations, workshops, and texts provided data for describing risk images (HAZID + RP), new technology, integrated operations, alterations, RG, and expert views. Identifying three risk image groups: technological optimism, traditional (business as usual), and reconfigured (greater complexity and uncertainty), the authors noted that risk images served to allocate attention to some hazards and divert attention from others (Tveiten & Schiefloe, 2014). Using a revised International Risk Governance Council (IRGC) model to assess oil field development, Renn, Grieger, Øien, and Andersen (2013) conducted stakeholder interviews, adopting a grounded theory approach to their case study. Reviewing benefit–risk trade-offs, risk–benefit governance, siting process, and compensation, the authors were able to assess project benefits as well as risks, ensure fairness and due process, and establish a common platform (e.g., "round table") for consulting stakeholders (Renn et al., 2013). Using a comparative approach (safety performance-based, risk-based, incident-based, resilience-based) to assess remote operations in the Norwegian offshore oil and gas exploration industry, Øien (2013) advocated flexibility and use of an appropriate mix of methods for optimum early warning system indicators.

Energy generation was the topic of 40 papers, with the majority of these (32) based in the nuclear sector, including a special *JRR* issue on nuclear power and nuclear safety in India, the contributions from which are discussed first. Reviewing public acceptance and the risk debate on nuclear hazards such as ionizing radiation, as well as fear, and learning from nuclear accidents, Mohan and Babu (2014) discussed the International Atomic Energy Agency (IAEA) action plan. The authors argued for strengthening peer review, emergency preparedness, and response, as well as more effective national regulatory bodies and operator effectiveness, reviewing and strengthening safety standards, a better international legal framework, facilitating infrastructure developments, capacity building, radiation protection, better RC and RAs, and better use of R&D (Mohan & Babu, 2014). Providing an historical context analysis in which India's 3-stage plan and legal liability were dominant features, Kumar (2014) referred to Fukushima, RC, India's nuclear expansion plan, nuclear fuel, India's peaceful nuclear explosion (PNE), Bhopal, the media, radiation, and nuclear waste. Noting the slowness of state systems in responding to public protests, which can create conditions for vested interests to further mobilize public resistance, the author noted that politics may prevail over science (Kumar, 2014).

Also referencing Bhopal, civil liability provided the framework for Sutaria's (2014) case of risk and hazard analysis of operator-supplier liability and nuclear law. The author argued for clarification of the legal liability framework, and a higher profile for disaster prevention (Sutaria, 2014). The same framework was applied for an international comparative study in which international nuclear liability law, nuclear cooperation, and the Compensation Convention were addressed (Mohan, 2014). The author noted that the divergence of opinion on correspondence between Rules and the Act required judicial interpretation (Mohan, 2014). International and national rules and standards analysis also provided the framework for A. Jha's (2014) review of legal dynamics and the judicial approach, and the 1994 Convention on Nuclear Safety (CNS). Considering inter/national law, regulatory institutions, public protest, distrust, fear, acceptance, safety expectations, transparency, and power structure, in the light of the Fukushima and TMI incidents, the author noted the reluctance of the judiciary to review scientific reports. This meant that revealing information on nuclear activity was problematic. While the CNS framework applied general safety considerations, obligations, and installations, its safety provisions were imprecise, and greater transparency was required for nuclear programs, which the IAEA should be able to audit (A. Jha, 2014). A legal case study was the backdrop for Mohan and Shandilya (2015) to review RA, the safety discourse, RP, public opposition, the Fukushima effect, and nuclear waste management. The authors noted that while the court accepted expert views on safety, it could not declare on matters of national policy (e.g., nuclear power generation).

Bilateral investment treaties (BITs), international arbitration, nuclear liability, and expropriation formed the case analytic legal framework for V. Jha (2014) to remark on the trend for BITs to be used to challenge domestic laws that had adverse implications for foreign investors (V. Jha, 2014). Reviewing the Japan–India civil nuclear energy cooperation agreement and nuclear safety from a politico-legal perspective, Nakanishi (2015) noted how government will was required for a mutually satisfactory bilateral agreement. Considering the health effects of low-dose radioactive exposure, the impact of the Fukushima incident, RC, and the need for an extended public/scientific debate about risk concepts, Yasui (2013) noted how definitions differed, with an epidemiological approach assigning risk as disease incidence rate, while a biological approach included DNA damage that could result in future cancers.

Addressing Fukushima within the context of ethics, hubris, and aspects of Japanese culture that included ingrained conventions, obedience, stick-with-program, insularity, and groupism, Kastenberg (2015) discussed emergent properties, risk-as-feeling, risk-as-analysis, and risk-as-politics. Raising RA issues relating to risks posed by technology and natural phenomena, and RM issues of acceptability, options to reduce risk, and criteria for choice, the author identified cases when safety culture (explicit, designed to address current task) and societal culture (implicit, evolves over time) were incongruent. In such instances, the latter can undermine the former. In the Fukushima case, cultural conditioning was incongruent with the safety culture required to manage the crisis. Mitigating this incongruity required a paradigm shift, and a cultural risk analysis, including cognitive (risk-as-analysis) and emotional (risk-as-feelings) aspects (Kastenberg, 2015).

Locating the Fukushima incident response within an historical analysis, Ramana and Kumar (2014) described a nuclear power plant fire case study, a high hazard technology involving organizational safety and reliability, organizational culture (safety culture, learning culture) the HRO model, RC, overconfidence, and learning from failure. The authors noted the need to define "accident" and "incident" correctly—as per IAEA criteria, and for regulatory authorities to enforce implementation of recommendations, as well as planning for possible na-tech incidents/accidents, heeding warnings, and generalizing failure (Ramana & Kumar, 2014).

With the Fukushima incident serving as a reference point, considering the public role in DM, information, knowledge, and trust in government, He, Mol, Zhang, and Lu (2014) noted that compared with OECD countries, knowledge levels in China were low and public opposition to nuclear power was place-based, being generally low but growing. The Fukushima case provided the base for a discussion of RC ethics, moral emotions (empathy, sympathy, responsibility), justice, fairness, autonomy, and legitimate risk messages by Fahlquist and Roeser (2015). From a three-level framework of morally responsible RC, the authors determined that while there were no neutral ways to design RC, ethically responsible RC required a legitimate procedure, participation, a justified risk message, and concern for evaluating message and procedural effects (Fahlquist & Roeser, 2015).

Using framing theory to content analyze news around the Fukushima nuclear accident, and radiation effects on health, Kim and Bie (2013) identified four major frames: negligible risks, predictable immediate risk, hidden danger, and open questions. From an egalitarian theory of justice perspective, Löfquist (2015) assessed Fukushima, CC, alternative energy sources, and na-tech scenarios, concluding that there was a need to address intragenerational and intergenerational issues of high electricity consumption, and an imperative to reduce electricity consumption by 25% using frugality and market mechanisms. Also from Sweden, considering contamination and health concerns from the Fukushima nuclear accident, Westerdahl (2014) adopted a systems change perspective to content analyze Internet news data on radioactive releases. The author noted that as a graded phenomenon, resilience can be an outcome, a state, a property or a process (Westerdahl, 2014). Using a dual process heuristic/systematic information processing model as an antecedent for attitude formation and RP change with respect to the Fukushima nuclear accident, Ryu and Kim (2015) found that systematic processing was affected by motivation, ability, message quality, and gender. Heuristic processing was affected by message quality, credibility, vividness, and age (Ryu & Kim, 2015).

From a review of international nuclear RM cases Hagmann (2012) provided a critique of the traditional impact × likelihood RA framework. Noting that nuclear power presented a combination of natural and technological risks, the author argued for more informed discourse on the potential and limitations of traditional RA (Hagmann, 2012). Using strategic DM analysis, prospect theory, and frame of reference to explore nuclear fuel cycle DM, risk acceptance, risk aversion, nuclear weapons, PNE, and political factors, Platte (2014) determined that nuclear self-reliance relied upon using available resources. The author noted that politically second-tier states will use their technology to maintain their international prestige, independence, and self-reliance, particularly when they perceive a direct threat (Platte, 2014).

Discourse analysis provided the methodology for interrogating nuclear organizations' and others' websites and texts for Eyles and Fried (2012) to explore social license, reputation, trust, self-representation, transparency, outreach, CC, rhetoric and reality, DM, RR, incident reporting, and science. The authors noted that uncertainties remained regarding disclosure and openness of safety as the basis for community trust and regulator independence (Eyles & Fried, 2012). Using the actor-network theory (ANT) and a strategic-relational approach to address nuclear policy, risk politics, and policy actors, Cotton (2015) constructed a hybrid punctuated evolution model of stability and change to represent human and nonhuman system elements to better understand periods of rapid change when interventions are made in periods of otherwise stable evolution.

Reviewing six CC mitigation scenarios within a context of nuclear technologies, nuclear weapon proliferation risk, costs, and efficiencies, Lehtveer and Hedenus (2015) developed a global energy transition (GET) model on a 100-year projection. The five GET model end users identified were electricity, transport, feedstock, residential-commercial heat, and industrial-heat. The authors maintained that rather than being globally decommissioned, nuclear power was likely to reduce the cost of reaching the strategic climate target (Lehtveer & Hedenus, 2015). Comparing lay people's and experts' knowledge, RP, and trust of medical x-rays and radiological risks from a nuclear accident, Perko, Adam, and Stassen (2015) reported that people with higher risk experiences had lower perception of radiological risks. The reception-acceptance model was the basis for Perko, Thijssen, Turcanu, and Van Gorp's (2014) interview case study of information processing, RP, and nuclear RC. The authors observed that while knowledge primarily drove risk reception messages, heuristic predictors (e.g., psychometric risk characteristics, attitudes, trust) most influenced acceptance of risk messages (Perko et al., 2014). Considering the U.S. Nuclear Regulatory Commission's (NRC) nuclear power licensing process, RP, public participation, regulation, trust, SC, and transparency, Smith (2015) observed that NRC DM was improved by the participation of a diverse range of interested and affected parties.

Nuclear waste disposal was a theme in a number of papers on nuclear energy. Considering group attitudes toward the nuclear fuel cycle (5 front-end and 5 back-end stages), from uranium mining, to nuclear waste, Litmanen, Solomon, and Kari (2014) identified diverse RPs from double risk deniers, double risk perceivers, and cross-over groups. Using SARF and ANT to describe organizational narratives, Wong (2015) considered public RP, nuclear accident, nuclear waste, and scientific humility. Concluding that nuclear power was risky but rational, the author identified core narratives as growth imperative, technological nationalism, and faith in systems and technology. While self-critique and reflexivity could open new spaces for change toward a more inclusive organizational discourse on nuclear risk, pollution but not CC was seen as a problem (Wong, 2015). In a radioactive waste disposal case study analysis, Landström and Bergmans (2015) reviewed geological disposal, siting, hosting, and long-term governance issues. Noting that sociotechnical challenges included complexity, residual risk, and perpetual uncertainty, the authors advocated engaging local communities, and legislating for the right to withdraw (Landström & Bergmans, 2015). The Dounrey nuclear site in Scotland was the case for Wylie, Haraldsen, and Howe (2015) to discuss DM, RP, hazardous facility, affected community, culture, place, and emotional attachment. The authors developed a 2-stage model to identify the directly affected population, and the sense and extent of lived community experience. Drawing attention to the adversarial planning processes that created tensions when rational administration met competing emotional and economic concerns, for equitable outcomes, Wylie et al. (2015) stressed the need to proactively identify those most directly affected, and to address the concerns of those at the center of the siting process.

Using decision theory dynamic RP, benefit perception, perceived adaptive capacity, and risk timescale to assess contested infrastructure projects, Moser, Stauffacher, Blumer, and Scholz (2015) found that over time perceived adaptive capacity, RP and benefit perception all accounted for variance in hazardous waste site acceptance. Also important were procedural fairness, trust, and community attitudes (Moser et al., 2015). Considering nuclear repositories, spent fuel, radioactive waste, time factor, containment system, and international conventions from a legal liability framework, Reyners (2014) noted that nuclear third party liability required an operator to maintain insurance or other cover to indemnify nuclear damage. However, for time limited statutes, a repository incident date was problematic (Reyners, 2014).

In an experimental manipulation of group beliefs to examine effects of temporal (linear, cyclical) representations on RP of nuclear waste Moser, Stauffacher, Krütle, and Scholz (2012) identified a causal relationship between a graphic representation of time and RP of nuclear waste. In addition to time perception, and gender differences, the stability of prior beliefs was also important (Moser et al., 2012). The crisis and emergency risk communication (CERC) framework and SARF were used to explore a depleted uranium case in which the social construction of risk involved RP, crisis, RC, and the media (Cicognani & Zani, 2015). The three phases of the case were precrisis (RC absent), crisis (media dominated), and post-crisis (institutional RC, commission report). Cicognani and Zani (2015) concluded that RM should build prior relationships with stakeholders (e.g., media).

Hazardous energy and waste issues also arose within the context of non-nuclear energy generation and use. Using a qualitative FTA as a generic RA and hazard evaluation for waste storage, Lerena, Auerkari, Knaust, Vela, and Krause (2013) considered hazardous materials, hazard assessment, hydrogen, storage, and electricity supply. The authors suggested using this methodology to reduce fire, explosion, and hazardous release risks (Lerena et al., 2013). Electricity consumption emerged as a theme in the context of e-waste from home appliances, along with product life and risk–risk trade-offs in Wada, Saito, Yamamotot, Morioka, and Tokai's (2012) model estimation and sensitivity analysis of consumption patterns. Comparing four lifestyles: (1) business as usual, (2) rapid cycling, (3) chain of users, and (4) quality and wisdom, the authors identified quality and wisdom as the best lifestyle for reducing both e-waste and CO_2 emissions. Rapid cycling was best for e-waste reduction, while chain of users was best for reducing CO_2 emissions (Wada et al., 2012).

Non-nuclear power generation included enhanced geothermal (power) systems (EGS), which were the subject of relative risk mapping and modeling a geothermal resource data file by Hoşgör, Apt, and Fischhoff (2013). To counter risks induced or triggered by seismicity, the authors recommended using a local tool for EGS siting and for RC in creating viable social process to secure consent (Hoşgör et al., 2013). Decision theory provided the context for a power generation case study of organizational risk-based DM, RC, experience, deference to expertise, and staff/management coordination (Mauelshagen, Denyer, Carter, & Pollard, 2013). The authors identified collective (organizational) experience and expertise as critical to DM, particularly for sharing knowledge to address complex, novel, nonroutine, and dynamic risks. Respect for, and sharing of, experience was a critical aspect of organizational culture (Mauelshagen et al., 2013).

Citizen panels were described as key to assessing trust of experts and public attitudes and RP toward hydrogen energy as a new/emerging technology (Flynn, Ricci, & Bellaby, 2013). To meet stakeholder and citizen demands for greater familiarity with new technologies, the authors advocated broad "whole systems" appraisals of hydrogen infrastructure (Flynn et al., 2013). Adopting a probabilistic risk assessment framework to examine the vast Desertec energy infrastructure project in Northern Africa, Stegen, Gilmartin, and Carlucci (2012) considered the security of European dependence on this energy source within the context of terrorism, power transmission, renewable energy, risk evaluation, physical and cyber vulnerability, and mitigation strategies. The authors concluded that regions connected with HVDC lines would be less susceptible to cascading blackouts than those with AC connections, noting that contingency planning can identify and compensate for weak spots on grids. While ever more sophisticated terrorist tracking centers are needed to assess strategic intent, the greatest returns arise from protecting the vulnerability of the system and its parts—that is, improving security and contingency planning (Stegen et al., 2012).

Disaster planning is often generic, so that the source of the threat (whether natural, technological, or na-tech) is less important than the response. An example is a case study in emergency RA that considered crisis management and civil protection of vital services and the environment from either chemical hazard or flood risk (Tammepuu & Sepp, 2013). Considering spatial planning and mapping within a context of EU legislation and guidelines, the authors advocated greater cooperation among EU states in developing emergency RA guidelines to formulate multihazard and multimapping solutions applicable to regional and local planning (Tammepuu & Sepp, 2013).

Adopting a scenario building methodology to address threats from all hazard types (e.g., social unrest, solar storm, pandemic flu), a national risk assessment study considered the protection of five vital interests (territorial security, economic—e.g., business continuity, ecological, physical safety, and social/political stability), within the 2007 Dutch national security strategy RG framework (Mennen & van Tuyll, 2015). Using capability analysis and a risk diagram (with likelihood and consequence axes), the authors assessed whether the country had adequate capacity to deal with a range of threats, and determined which capabilities needed strengthening to protect national vital interests (Mennen & van Tuyll, 2015). National databases from the Czech Republic, Hungary, and Poland, were used by Brazova, Matczak, and Takacs (2015) along with legal acts, documentary review, and expert and practitioner interviews, to describe civil security systems (CSS). Considering adaptation, and change drivers, CSS focusing events noted by the authors included floods, industrial accidents, major transport crashes, disease outbreaks, wildfires, and storms. Natural events were the most potent change drivers, perhaps associated with secondary events, such as pollution (Brazova et al., 2015).

From case studies (terrorism cycles, climate change), and scientific risk estimation to examine extreme (low probability, high impact) events within a conceptual framework embracing utility function modeling and prospect theory, Brandt (2014) used comparative risk, RP, RC, and RR to study public perceptions and involvement with respect to CC adaptation (lack of control, fear, denial, apathy), volatility, affect, and protection level. Noting challenges from disproportionate policy response to extreme risks, including additional costs, that implementation lags change in risk level, and lock-in to inefficient technologies, the author observed that while defense against terrorism required continual success, an attack only needed to succeed once. Recommendations included tailoring RC to risk, and emphasizing positives and control (Brandt, 2014). Using a qualitative/quantitative case study methodology (interview, observation, survey) to explore recovery from a poisonous gas explosion, Bang and Few (2012) adopted an impoverishment and reconstruction model to study disaster risk reduction. The authors highlighted the need to develop strategies to address complex socio-economic and cultural consequences of disaster recovery.

From the disaster resilience of place (DROP) model and the U.S. Enhanced Critical Infrastructure Protection program to assess policy, threat mitigation, and global connectedness of risks, Prior and Hagmann (2014) developed a resilience index. Their qualitative and quantitative case study data identified DROP resilience dimensions as social, economic, institutional, infrastructure, and community capital (Prior & Hagmann, 2014). The range of global risks was the topic of papers from France, Finland, and Taiwan. In a summary critique Mudu and Beck (2012) observed the complexity of managing investigations within a context of the uniqueness of all risks. A national survey comparing RP and risk emotions (e.g., fear, worry) identified the main risks as environmental/ecological threats, terrorism, and infectious diseases (Räsänen, Näsi, & Sarpila, 2012).

Triangulating interviews with survey data, and using analytic induction with the constant comparative analysis method, Huang (2012) identified ambivalence in teachers' RP, reflected in their teaching. The author advocated teaching teachers more about risk within a context of cultural pluralism (Huang, 2012). A more offbeat reflection on disaster prevention/management using scenario analysis to consider extraterrestrial risks, including microbiological forms, was provided by Neal (2014). The case was presented as an example of a risk in which ambiguity and uncertainty prevail and one for which no potential threat preparation existed. When earth-centric ecology models are challenged, intergovernmental protocols are essential in planning for possible extraterrestrial encounters. The risk is one for which new evidence could immediately generate a paradigm shift in thinking (Neal, 2014).

11.3.4 Emerging and emergent technology risks

Sixteen papers addressed emerging risks and hazards associated with new technologies. Three specifically mentioned nanotechnology. A constructivist (risk cognition + value) framework involving language categorization and conceptualization was the basis for Boholm (2013) to undertake a RC media coverage textual analysis. The study revealed a diverse range of associations between "nano" and risk, with health and environment the dominant values (Boholm, 2013). A case study of EC legislation, RR, and EU policy making formed the basis for Rodríguez (2015) to examine the risks/benefits balance of nanotechnology, including objective risk, constituted risk, uncertainty, and socio-economic factors. The author declared that RG should respond to a clear separation between RA and RM. Technological innovation risk should be framed and appraised by regulatory bodies and founded on scientific representation (Rodríguez, 2015).

In their comparative survey of emerging technologies, Besley and McComas (2015) included nuclear energy as well as nanotechnology, to consider RC, familiarity, risk–benefit perceptions, and scientific knowledge. The authors found that as a technology becomes more familiar, rational/cognitive perspectives increase in importance (Besley & McComas, 2015). Modeling of household survey data on RPs, agentic risks (e.g., smoking), IDs, hazard categories, and manufacturing risks enabled Cummings, Berube, and Lavelle (2013) to specify emerging technological risks as more easily predicted than other risk categories, with IDs varying in explanatory power between risk categories.

Another specific emergent risk identified was hydrogen energy, with Flynn, Ricci, and Bellaby (2012) considering issues of trust, ambiguity, complexity, uncertainty, and regulation. Reviewing evidence from citizen panels within the IRGC framework for emergent risks, the authors argued the case for integrating the PP within RA/RM. It was concluded that lay views on expert views were ambivalent, contradictory, and subject to critical trust (Flynn et al., 2012). Addressing health issues associated with exposure to mobile phone base stations, Dohle, Keller, and Siegrist (2012) used appraisal models to determine emotions (fear, anger), RP, benefits, cognitive appraisal, controllability, fairness, and acceptance of this technology. The authors found that acceptance was directly determined by risks, benefits, and anger (negatively), and indirectly by fear, certainty, control, and fairness (Dohle et al., 2012).

Unmanned aerial vehicles were the solution to the emergent risk of gas pipeline incidents recommended by Zaréa et al. (2013). The authors described image collection and processing of data from automated aerial surveillance drones (cf. Chapter 3) as a means of enhancing industrial safety as well as helping to meet KPIs (Zaréa et al., 2013). The threat detection system involving a change detection algorithm, these authors described as an example of emerging risk management framework (ERMF). The ERMF, along with emerging risks representative industrial applications (ERRAs) and iNTeg-Risk was also adopted by Scheer (2013), who incorporated RG, RC, risk ranking, emerging risks dimensions, public tolerability, and acceptance. The author determined that a holistic and comprehensive RG approach was needed, with the main components being preassessment, RA, RM, RC, and risk characterization/valuation (Scheer, 2013).

The ERRA and iNTeg-Risk framework as well as the solvency directive, IRGC and ISO 31000 criteria, also found favor with Jovanović and Pileć (2013) in their study of risk–risk trade-offs, emerging risks, multiple risks, high complexity network, technology lifecycle, and ancillary risks. In a risk trade-off analysis, these authors argued the need to identify relevant KPIs/safety performance indicators, and then define and select the RA/ERRAs framework. Seeking a grand scale top-down approach that acknowledged risk interconnectedness, the authors described the creation of global governance gaps and a "1StopShop" RA—Safetypedia. Within the spirit of the WEF framework, the authors argued that to improve coordination and macro-prudential supervision in establishing effective global policies, it was essential to consider multiple risks concurrently (Jovanović & Pileć, 2013).

The EU iNTeg-Risk project involves a common framework for four key components: RG/RC, technology, policy/legal, and human/RM. This project was the topic of a special issue of *JRR*, in which were considered, inter alia, societal risks, anticipation, multiple safety criteria for emerging risks (responsibility, efficiency, transparency, socially fair), RG, and new RM tools (Jovanović & Renn, 2013). The editors' overview of innovation strategies of the iNTeg-Risk project included insurance, lifecycle risks, and standardization, as well as early recognition, and monitoring. The authors concluded that EU nations were mostly risk-averse, particularly to emergent risks, and that exposure to any risk could impact risk aversion. The difficulty of meeting high expectation of safety for new technologies and the need to convince stakeholders and the public was noted. The authors concluded that knowing and managing emerging risks could be a European trademark for competence and competitiveness. For this, a unitary approach was needed that could become a global standard for good practice (Jovanović & Renn, 2013). The notion of a Safetypedia knowledge base to incorporate new technologies, integrate RM, harmonization, and risk trade-offs, within the iNTeg-Risk project was also addressed by Jovanović and Baloš (2013), who described a multimethod database of KPIs and early risk indicators (RiskEars). To progress EU standardization, and ensure interconnectedness, the authors argued for a top-down approach that could deal with a range of possible consequences, including health, safety, security, business, environment, image loss, and public disruption (Jovanović & Baloš, 2013).

Reviewing two IRGC reports on emerging risks, Florin (2013) identified 23 frequently recurring RG deficits that impacted many risk types. Ten of these were of RP and related factors, while 13 were RM deficits, plus 12 contributing factors. To improve RG/RM, the author urged better understanding of these deficits (Florin, 2013). A lifecycle assessment (LCA) framework incorporating RA and ISO 14040–14044 was the basis for Breedveld (2013) to assess the environmental impact of new and emerging technologies. From a comparative methods approach the author argued that combining RA and PP-based LCA as a lifecycle-based risk assessment would optimize early assessment of potential impacts on HS&E (Breedveld, 2013). Enhancing more traditional RA techniques was also the theme of Ström, Koivisto, and Andersson's (2013) modeling of HAZOP systems diagrams to reveal deviations from design intent for emerging risks. A unified modeling language could improve HAZOP by combining it with information modeling to meet international standards (Ström et al., 2013).

Developing RA, by monitoring emerging risks in the petrochemicals and power industry sectors by developing software for online monitoring was recommended by Stanojevic, Orlic, Misita, Tatalovic, and Lenkey (2013). Online information from different sources was needed to make risk decisions, connect systems, acknowledge KPIs, and take the unexpected into account (Stanojevic et al., 2013). An early warning RA emergent risks approach that could assess major accident hazards, natural hazards, and also na-tech events was commended by Salzano et al. (2013). The authors' risk ranking methodology, involving quantitative assessment of scenarios, led them to recommend RM strategies to address the growing likelihood of na-tech events (e.g., earthquake on industrial site) to enhance resilience (Salzano et al., 2013). A more polemical contribution to the technological risk debate from Renn and Benighaus (2013) considered attention/selection filters, cognitive heuristics, uncertainty, reality construction, RP dimensions, and cultural factors. Addressing the multidimensional nature of risk, the authors reviewed RC, RP/risk–benefit asymmetry, public acceptance, RP biases, and evolutionary strategies (flight, fight, play dead, experiment—cf. Chapter 4). To address the complexity, the authors argued that a structured framework was needed to provide an integrative and systematic perspective on technological RP. Research tools were essential for measuring RP and risk acceptance so that risk expertise could be integrated with public concerns and risk trade-offs (Renn & Benighaus, 2013).

11.3.5 Major biodiversity loss and ecosystem collapse

While no papers addressed this topic explicitly, 24 papers with an environmental theme, including various forms of pollution, were subsumed under this heading as factors that could adversely affect biodiversity and ecosystems in the long term. Of four papers addressing environmental pollution and related health issues, Signorino (2012) surveyed RP of the petrochemical industry. Addressing RC issues, the author urged involvement of local communities in RM plans (Signorino, 2012). With the *Deepwater Horizon* incident as an oil and gas industry exemplar, Reader and O'Connor (2014) considered SA, active and latent failures, RA, DM, RP, teamwork, pollution, confirmation bias, bounded awareness, leadership deficits, regulation, and production as priorities. Referencing HF, systems, non-technical skills theorem, safety culture, and the complex mishap framework, the authors determined that the multiple causation *Deepwater Horizon* incident resulted from a failure to learn from prior incidents, over-reliance on informal RA and inadequate RC and safety culture, as well as risk misperception, which led to poor DM and outweighed short-term consideration of risks (Reader & O'Connor, 2014).

A site contaminated from a tire fire industrial accident was examined by Vangeli, Koutsidou, Gemitzi, and Tsagarakis (2014), who explored atmospheric pollution by modeling RP, GIS, and WTP variables. While consumption of some foods ceased near the contaminated site, the authors revealed that a majority of their sample thought that the site should be rehabilitated. WTP was unrelated to distance from the accident. The importance of strong local community involvement was emphasized (Vangeli et al., 2014). The effect of atmospheric pollution on well-being, health RP, quality of life, and perceived health was surveyed by Fleury-Bahi, Préau, Annabi-Attia, Marcouyeux, and Wittenberg (2015) using transactional models of well-being, environmental satisfaction, and stress. The authors found that subjective annoyance and health RP from air pollution were important when effects of socio-economic and ecological vulnerability in polluted cities were combined (Fleury-Bahi et al., 2015).

The sustainability theme characterized another five papers. Contaminated land, RP, RA, and sustainable remediation were addressed by Filipsson, Ljunggren, and Öberg (2014), whose survey methodology revealed that gender, age, and experience affected RP, RA, and risk evaluation. Science-policy theory and the ecosystems approach to management was the conceptual framework for Linke, Gilek, Karlsson, and Udovyk's (2014) marine ecosystem Baltic Sea fisheries case study, in which eutrophication and other sustainability threats were considered within a context of RG, uncertainty, scientific assessment, organizational structures, and institutional frameworks. The authors concluded that conventional science-based policy-making was inadequate for complex environmental governance areas, and that a major political challenge involved addressing social aspects of uncertainty and stakeholder disagreements in environmental RG. The scientific authority paradox identified was that where science was most needed it was also most liable to be challenged (Linke et al., 2014).

The multidisciplinary nature of the field was emphasized by Gemmell and Scott (2011) who addressed sustainability and resilience within the context of international CC debates, which also provided the context for Gemmell and Scott (2012) to consider energy supply sustainability and food security. The authors considered that inaction was more costly than acting now, while economic development should move to a low-emission and climate-resilient path. CC issues were too large and abstract for private DM (Gemmell & Scott, 2012). Kishimoto's (2013) review of risk–risk trade-off analysis considered gaps between substances, domains, risks and benefits, and time and space. Within the context of a low-risk society, issues of safety, increasing expectations, increasing invisibility of risks (e.g., climate change), rising costs of risk reduction, and unintended counter-risks were all relevant. To achieve sustainability, the authors argued for a common platform at all levels for debating different risk types along spatial and temporal axes. Safety and RA concepts needed to be broadened to include sustainability and risk–risk trade-offs (Kishimoto, 2013).

In a survey of environmental agencies in China to assess emergency response and environmental RM (ERM), He, Zhang, Mol, and Lu (2013) tested the adequacy of these against nine ERM tools. The authors determined that environmental risks were not given sufficient weight and that ERM tool application was limited. Environmental agencies adopted diverse strategies, whereas better unified national policies were required for capacity building (He et al., 2013). Content analysis of news stories and framing was used by Hove, Paek, Yun, and Jwa (2015) to explore stakeholder uncertainty about carcinogens within a context of RC, RP, and emotion. The authors found that while reassurance was the most used frame, more effective environmental RC would emerge from better cooperation between experts and journalists (Hove et al., 2015).

Environmental values, trust, RP, RC, systematic and heuristic processing, featured in Tortosa-Edo, López-Navarro, Llorens-Monzonís, and Rodríguez-Artola's (2014) study of environmental issues from the petrochemical industry. Heuristic-systematic theory formed the conceptual basis for the authors to conclude that the petrochemical industry should engage in frank, bidirectional RC with local residents to break the association between pro-environmental values, distrust in companies, and RP (Tortosa-Edo et al., 2014). Energy sources were the focus of Burger's (2012b) survey of attitudes and perceptions about environmental issues to inform government energy policy. Political controversy and RR politics surrounding land use for biofuel production or co-production was entered into by Palmer (2012) as part of the socio-economic RG environment debate. The author defined indirect land-use change as a "wicked" problem not resolvable by RA, but characterized by closed broader political debates and uncertainties (Palmer, 2012).

A social constructionist framework informed a Chinese survey of 25 risks, including anthropogenic risks within a context of public RP, emergency response, limited risk knowledge, top-down approach, distrust in government, and personal hazard experience (Zhang, He, Mol, & Lu, 2013). The study revealed less public concern about the long-term impact of risks that were seen as less visible and less scientifically certain. Little effort was expended by the government to understand public knowledge of ERM, while substantial barriers to public participation in RG remained, along with fundamental widespread public distrust in the Chinese government (Zhang et al., 2013). Contemporaneously, a U.S. longitudinal study of public opinion using data from nine Gallup surveys, examined political ideology, worry, and system-justification tendencies, with a focus on the so-called conservative white male (CWM) effect (McCright & Dunlap, 2013). Exploring the CWM effect in RP using an identity protective cognitive thesis, the authors identified CWMs' low concern with environment risks as driven by their social commitment to prevent new environmental regulations, and to repeal existing ones, which was consistent with CC denial (McCright & Dunlap, 2013).

A constructionist "resonance" model interpretive approach was used to inform an international comparative survey of EU environment health experts to explore risk policies, SARF, RP, RP attenuation, policy agendas, risk ranking, social learning, framing, media, distrust, and culture effects (Bröer, Moerman, Spruijt, & van Poll, 2014). The authors found that policy affected RP, while divergence in risk rankings between citizens and experts was greater in the Netherlands and United Kingdom than in Spain and Slovakia, with distrust highest in Slovakia (Bröer et al., 2014). Indian case law analysis informed Chowdhury's (2014) study of RR in environmental impact assessment, which also considered public goods, legal system access, media, and "expertization." The author opined that increasing reliance on technical experts for RA devalued public participation, which was essential to risk debates (Chowdhury, 2014).

Understanding and incorporating uncertainty within environmental risk models emerged as a theme in some papers. To examine probability assessments under conditions of uncertainty, Dieckmann, Peters, Gregory, and Tusler (2012) developed web-based experiments using environmental management scenarios. The authors determined that uncertainty could be simplified by using numerical ranges to identify relative likelihoods with evaluative labels (e.g., "high," "low") to reduce attribute uncertainty (Dieckmann et al., 2012). A special *JRR* issue on risks, environmental decisions and uncertainties led Siegrist (2012) to advocate a comparative DM approach to take account of a variety of risk paradigms covering RA, RP, RM, and RG.

Economic analysis, system analysis, and decision analysis formed the conceptual basis for Whitten, Hertzier, and Strunz (2012) to explore resilience, complex systems, environmental risks, and uncertainty, using cost, option and shadow prices, and NPV tools. From the available options, the authors advocated resilience thinking as a robust framework for understanding risks and system changes (Whitten et al., 2012). Using uncertainty analysis (understand, identify, manage) in a review of 30 uncertainty typologies, Skinner, Rocks, and Pollard (2014) discussed uncertainty levels, known and unknown outcomes and probabilities, and developed a summary ERA typology. The authors found that uncertainty typologies used contradictory terminology, differed in uncertainties and dimensions used, failed to use information sources systematically and uniformly, and could not be individually applied to ERA (Skinner et al., 2014).

11.3.6 Water crises

From two case studies within a safety framing and RC context involving recycled water, WTP and park visits, Tsagarakis, Menegaki, Siarapi, and Zacharopoulou (2013) concluded that communicating safety precautions about a new product prompted people to appraise risks emotionally (e.g., in terms of fear or opposition) rather than cognitively. They advocated publicizing similar successes and emphasizing gains to enhance personal relevance, familiarity, and ecological benefits (Tsagarakis et al., 2013). A longitudinal case study using media reports and focus groups to address Ontario drinking water contamination within a context of RP, trust, and blame, concluded that while blame evolved over time, trust was lost immediately and took a long time to recover.

A single case can become an anchor for reference with public suspicion of governance being part of a healthy democracy (Driedger, Mazur, & Mistry, 2014). Addressing water pollution risk in China within a context of RP, and judgments about time/space probability trade-offs, She, Lu, and Ma (2012) manipulated temporal and spatial distances experimentally. Using a probability time-and-space trade-off model, it was concluded that people believe that they are less likely to suffer health problems when temporal and spatial distances of pollutants extend over longer time periods (She et al., 2012). By analyzing an odor sampling database to examine odor perception, and individual differences in odor sensitivity (20% level accepted) in a U.S. water reclamation plant, and based on odor reference concentration (similar to reference concentration for chemicals), T. Wang et al. (2013) developed an odor hazard index—an RA tool to identify, predict, and interpret risk magnitude using odor concentration, determining this to be an adequate control strategy.

A study of groundwater supply in the Czech Republic examined natural and anthropogenic hazard sources using a combination of methods and data sources that included FTA, brainstorming, RA, criticality assessment, crisis and emergency planning, sensitivity assessment, and a hazard register (Bozek, Bumbova, Bakos, Bozek, & Dvorak, 2015). The authors argued the importance of a semi-quantitative RA for classifying groundwater resources proposed for emergency water supply (Bozek et al., 2015). Comparing groundwater vulnerability and contamination assessment methods, Shirazi, Imran, and Akib (2012) explored the GIS-based DRASTIC index, which uses seven hydrogeological parameters to assess groundwater vulnerability. The authors employed a modified DRASTIC method and sensitivity analysis to assess groundwater in arid, semi-arid, basaltic, agricultural, and landfill regions (Shirazi et al., 2012).

11.3.7 Climate change mitigation and adaptation failure

A questionnaire to politicians in Ethiopia, one of the countries most affected by CC, addressed rainfall variability, declining hydrology, increasing temperatures, and emotions (dread, helplessness). Further targeted education was deemed to be critical (Aberra, 2012). With a focus on climate RM and CC effects on agriculture in Africa, Murendo, Keil, and Zeller (2011) discussed drought, food security, livestock death, soil and water conservation practices, crop yields, agriculture, adaptation strategies, and resilience. Using asset-based and social RM approaches, the authors argued for training farmers in production and conservation of livestock fodder and rearing drought tolerant livestock, with soil and water conservation practices being essential to coping with drought. They noted that farmers were very aware of CC effects on their livelihood, also urging drought forecasting and facilitating financial smoothing assistance (Murendo et al., 2011).

In Winnipeg, a case study involving expert interviews, public questionnaires on RP, and influence diagrams, assessed the impact of heatwaves on health and developed mental models of expert knowledge to model the heatwave hazard (Chowdhury, Haque, & Driedger, 2012). The authors urged improvements in heatwave RA and mitigation capacity by developing interactive RC tools and public engagement in CC knowledge enhancement. A Brazilian case study also used interviews to examine threats to water supply, food security, human health, natural resources, sea level rise, and coastal cities. The complex climate agenda included reference to politics, planned adaptation to greater climate variability, natural hazard protection, RR, RG, framing, mitigation, RA, intentions, and actions (Barbi & da Costa Ferreira, 2014). Framing CC risks in terms of policy responses, the authors concluded that multilevel and intersectoral responses were required to address CC risks, rather than blending them with local government strategies on typical problems (e.g., flooding, landslides).

Key local centers should focus on development/design, built environment, infrastructure, transport, and carbon sequestration (Barbi & da Costa Ferreira, 2014). Developing a model based on extreme weather-related events, GIS, integrated vulnerability assessment, mapping, resilience, and community adaptation, Rød, Opach, and Neset (2015) created an integrated vulnerability index including data on storms, floods, and landslides, as well as the built environment and socio-economic factors. The authors' web-based visualization tool (ViewExposed) combined top-down exposure and vulnerability assessment with participatory bottom-up assessments, both of which are crucial to supporting decisions about implementing adaptive/preventive measures against CC-related hazards (Rød et al., 2015).

CC mitigation was examined from a social cognitive theory framework including self-efficacy, collective efficacy, costs, benefits, barriers, outcome expectancy, and social dilemma by Koletsou and Mancy (2011), who argued that managing CC risk required understanding how to encourage positive collective behavior change. Individual differences mean that different strategies are required for different groups (Koletsou & Mancy, 2011). From a welfare, cost-benefit analysis, and regulatory framework, Pryce and Chen (2011) studied flood risk, land use planning, housing (prices), risks distant in time and space, environmental migration, long-term insurance premium adjustment, well-being, resilience, adaptation, and displacement. The authors noted the imperative of developing adaptation measures (e.g., flood walls, culverts, reservoirs), it being too late for flood risk mitigation, and CC information alone is not enough. While flood warnings will be required, individuals needed to take some responsibility for their own flood defenses and some areas would need to be abandoned (Pryce & Chen, 2011).

A mock case study in a 2-day workshop for stakeholders in Scotland addressed RR, carbon capture and storage, and CC mitigation (Vannan & Gemmell, 2012). Applying emergency planning principles to regulatory framework assessment, the authors argued for early and frequent discussions with all stakeholders, with initial projects managed collectively. The main gaps identified were regulatory coordination, information sharing, and community engagement (Vannan & Gemmell, 2012). From a CC policy perspective using the risk information seeking and processing (RISP) model, Yang, Seo, Rickard, and Harrison (2015) identified key variables as RP salience, knowledge, negative affect, information processing, message elaboration, and policy support. The RISP model posits information insufficiency as a central motivator for information processing. It was revealed that perceived issue salience triggered negative affect and information insufficiency, which prompted systematic processing leading to greater policy support and stronger motivation to adopt more pro-environmental behaviors (Yang, Seo, et al., 2015).

Generic building safety was the topic of an Australian study which focused on CC-driven risk–resilience trade-offs (Gibbs, 2012). A probabilistic (risk-based) approach to avoid skew to resilience used climate model projections for building design, and environmental variables (e.g., wind speeds, wave heights, flood levels). The author cautioned that historical data may not be valid for future risks, and that as codes required constant updating, it was preferable to consider asset lifespan as the basis for RM (Gibbs, 2012).

11.4 Geopolitical

Only five papers from the sample addressed risks under this WEF heading. Considering offender RA within the context of the dominant discourse of the UK criminal justice system, Lewis (2014) identified a fourfold generational typology of RAs: (1) professional judgement; (2) static actuarial risk models; (3) criminogenic risk/needs assessments; and (4) a multidisciplinary approach incorporating responsivity. The author noted that expert discourse produced a singular account of risk and R-T, while alternative ways of thinking about risk and R-T behavior had been displaced by single actuarial-based approaches. Thus, creative ways of thinking about risk had been largely abandoned in favor of cost-effective and speedy technologies that could be manipulated to create systems intended for governance (Lewis, 2014).

Using qualitative data from interviews and police files, Klima (2012) considered vulnerability, resilience, business sustainability, and uncertainty within the context of organized crime in Belgian transport and hotels. While precrime vulnerability factors included opportunity, and inadequate controls, post-crime factors were inadequate recovery, and adaptation (Klima, 2012). Analyzing 5 years of data from the Korean Customs Service, Han and Ireland (2014) reviewed emerging/evolving risks, fraud, smuggling, selection/detection rate, and international trade effects. Customs RM guides described three detection methods: random, rule-based, and manual. While manual selection was identified as the most effective option, the other methods were also useful. A rule-based approach was useful for fraud detection, while the random method had deterrent effect due to its unpredictability. It was concluded that complementary deployment maximized efficiency (Han & Ireland, 2014).

The sole paper on terrorism risk, from Turkey, used a Q-sort methodology matrix and factor analysis to generate a structured analytical model and functional typology of terrorist organizations (Koçak, 2012). The threat and RP analysis identified five types: ethno-separatist, provocative religious, intimidator religious, self-conscious religious, and communist (Koçak, 2012). A case analysis of social unrest (riots) within a CM context involving authority crisis and social control, considered individual action, welfare, identity, ideology, values, community, justice, and responsibility (Durodié, 2012). Noting the importance of seeking underlying "causes" for social unrest, the author observed that building community resilience could be problematic (Durodié, 2012).

11.5 Societal

11.5.1 Food crises

While no papers addressed fundamental issues associated with severe food crises, several considered various aspects of food safety, mainly within the context of agriculture or aquaculture. Using molar ratios chemical testing and analysis of fish to identify mercury (Hg) contamination and selenium (Se) protective effects, Burger (2012a) discovered that considerable variation in Se:Hg ratios implied unpredictable ratios for individual fish. Adopting the U.S. Environmental Protection Agency reference dose to compute Hg intake, Burger (2013) explored fish consumption and estimated Hg intake among recreational anglers. It was revealed that risk balancing (omega-3 vs. Hg) for self-caught fish consumption and risk varied by month and species (Burger, 2013). Estimating exposure to methyl mercury as a result of fish consumption, Burger, Gochfeld, Jeitner, Donio, and Pittfield (2014a) found that sushi consumption could pose a significant risk from Hg exposure, urging more adequate RC in public health campaigns. Comparing RA models in the Hg at Oak Ridge case study, Burger et al. (2014b) adopted the risk prioritization model to explore Hg contamination, risk evaluation outcomes, fish consumption, and RC. The authors compared the purpose, goals, receptors, and assumptions of each risk evaluation approach, before recommending an RM strategy that allowed iterations as new information became available (Burger et al., 2014b).

Eight types of RA were used in a study of farm food safety, which considered aquaculture, RAs, H&S, water availability and quality, pest control, worker hygiene, site assessment, pesticides, veterinary medicines, fresh produce, and fish health (Soon & Baines, 2012). Noting that auditors looked for changes in records to ensure real-time RAs, the authors recommended reducing paper RAs by consolidation. While fresh produce farms were motivated by customer requirements, salmonoid farms were motivated by regulations (Soon & Baines, 2012). Dairy farmers' RP and risk taking in Ethiopia were surveyed by Gebreegziabher and Tadesse (2014), who identified risk sources as technological, price/market, production, institutional financial, and human. While RP was farmer-specific, the most effective RM strategies were disease reduction, diversification, market networking, and financial management (Gebreegziabher & Tadesse, 2014).

In designing a farm risk map Leppälä, Murtonen, and Kauranen (2012) considered risk identification, sustainable management, and people safety assessment. The farm risk map categories comprised farm assets, finance, products, production quality, people safety, and external risks (Leppälä et al., 2012). Undertaking a risk and social impact assessment at societal and institutional levels, Mahmoudi, Renn, Hoffmann, Van Passel, and Azadi (2015) used a triangulated methodology in a case study of organic agriculture, which included sustainability, screening, shadow (hidden) risk, food safety, and social benefits. The authors discovered several ambiguities: domestic need versus global market, food security versus insecurity, small- versus large-scale farms, and international versus national standards. Using SARF, shadow risks tended to be attenuated, for example, socio-economic risks that included food insecurity, lack of social justice, and an imbalance between large and small scale farming communities (Mahmoudi et al., 2015).

Global interconnectedness, social context, and wealth inequalities formed the framework for Mauro's (2012) study of soil acidification, agrochemicals, crop failure, and water pollution, which the author attributed to anthropogenic degradation. To confront these problems it was necessary to address historical and multiple-scale social processes, consult communities, and aim at institutions with global reach (Mauro, 2012). A survey of agricultural RP, risk attitude, intention to apply RM strategies, risk aversion, and experience by van Winsen et al. (2015) revealed that while risk attitude significantly impacted intention to apply RM strategies, RP of business risks did not. An agriculture survey using a modified TPB framework to identify risky option preferences considered these to be a function of expected benefits and perceived risk (Hansson & Lagerkvist, 2012). Identifying risk sources as financial, production, environmental (including weather), and social (e.g., family), the authors assessed risks as domain-specific, noting that farmers were risk averse, for example seeking to be up-to-date and in control, taking care, being progressive, and planning (Hansson & Lagerkvist, 2012).

Comparative risk and SARF formed the conceptual basis for Zingg, Cousin, Connor, and Siegrist's (2013) food safety survey of meat consumption and the meat supply chain, which included RP, consumer confidence, trust, and animal welfare. The authors found IDs in RP so that less risk was perceived at home than in earlier stages of the chain. However, food safety perceptions were less significant than other variables, including traceability, labeling, and public involvement in RM DM (Zingg et al., 2013). A political context for consumer engagement in policy DM using a hierarchy of participative practices model provided the basis for Rothstein's (2013) analysis of four food safety case studies (food allergens, BSE, Consumer Committee, Advisory Committee on Consumer Engagement) incorporating stakeholder DM. The author explored public/consumer participation, science-based policy making, regulation, the role of UK government agencies (FSA, MAFF), consumer panels, and ad hoc consultation. Concluding that participation impact depended on adaptability to entrenched policy-making norms, practices and cultures, the legitimacy for participative approaches was problematic, and institutional fit was required to match participative and policy practices (Rothstein, 2013).

Using both top-down and bottom-up models, Martinez, Verbruggen, and Fearne (2013) examined EU risk-based food safety regulation, transparency, and voluntary compliance, concluding that effective co-regulation required complementarities between direct and prescriptive regulation. The framework required data sharing between public and private stakeholders and responsiveness to changing risk profiles and industry environments (Martinez et al., 2013). Risk-as-analysis and risk-as-feeling theory, and the affect heuristic formed the conceptual basis for De Vocht, Cauberghe, Uyttendaele, and Sas's (2015) cross-cultural comparative food safety survey. Comparing RC, CC RP, trust in government, and subjective knowledge in Belgium, Spain, Serbia, and Norway, the authors found correlated affective and cognitive reactions. More than affect, cognitive reactions predicted behavioral intent and information-seeking intent. It was concluded that differences between countries predicated national rather than international RC strategies (De Vocht et al., 2015).

Risk profiling, risk coefficient, and FTA were the methodological tools for Qi, Vitousek, and Liu (2015) to explore food insecurity in China. Risk factors included natural disaster, resource and input constraints, demand, and trade. The authors advocated agricultural infrastructure and flood early warning systems to alleviate risk, and policies to control excess fertilizer use (Qi et al., 2015). A CM framework to study food safety crises was adopted by Regan, Raats, Shan, Wall, and McConnon (2015) to explore RC, social media, and stakeholders. It was discovered that social media could be integrated in crisis RC and that the interactive component could be used. The authors argued for the importance of listening to consumers, and for crisis RC to be widespread, prompt, and managed to control confusion and alarm (Regan et al., 2015). Stakeholder analysis, RG, and DM process were features of a comparative study of five EU states in which Van Wassenhove, Dressel, Perazzinin, and Ru (2012) examined BSE, RC, RP, and trust. The authors advocated a transmissible spongiform encephalography roadmap effective for stakeholder RC (Van Wassenhove et al., 2012). The PP was adopted in Kim's (2012) study of BSE, which recommended hazard analysis and critical control point policy and lifecycle RM for reducing trade risk.

The topic of a number of papers relating to RP of food safety was GM foods, often in an agricultural context. Warning label research to explore food labeling and product perceptions was described by Hellier et al. (2012), whose experimental manipulation of color, wording style, and information source in influencing RP and purchase intent showed that label design affected the perception of GM foods. Surveying PR, perceived benefits, trust, sense of bioethics, and acceptance of GM and plant breeding crops and biotechnology, Tanaka (2013) found that a Japanese sample had a more negative attitude toward GM crops than toward conventional crops. While RP was most important in GM crop acceptance, trust was most important in conventional plant acceptance (Tanaka, 2013). A comparative analysis of regulatory and sector-specific approaches led D. Winkler (2013) to explore the EU Deliberate Release Directive 2001/18/EC, with respect to GMOs, genetic engineering, and anticipated future hazards. Undertaking a technological assessment of cases covered by the European Law of Agricultural Genetic Engineering, the author addressed risk culture, the sociopolitical approach, RR, RA, and a harmonized science-based approach. It was noted that the dichotomy of coexisting European RR approaches to GM plants—being both scientific (individual case RAs) and socio-cultural (general assessment), the directive did not bring harmonization (D. Winkler, 2013).

A Chinese study of GM food examined RP, RC, and trust in authorities, the authors finding that while social trust mediated shared value and RP, shared value improved the competence and care dimensions of trust (Lu, Xie, & Xiong, 2015). Adopting a discourse analysis methodology within a risk society framework, and using Van Leeuwen's legitimation categories: authorization, moral evaluation, rationalization, and mythopoesis (narratives that reward), Desmond (2015) studied the case of Bt cotton legitimation in India. The depolitization of ambiguous risk involved a trade-off between poverty alleviation and animal deaths. However, the change in risk–risk trade-offs over time as economic benefits waned and risks accumulated required a longer-term perspective. Caution is also needed in extending Bt technology to food crops such as Bt brinjal and Bt chickpeas (Desmond, 2015).

11.5.2 Pandemic outbreaks

Several papers addressing this topic could be linked with the food safety heading because some pandemic outbreaks are food related. A grounded approach, involving narrative creation and response framework, was adopted by Burns, Ribble, McLaws, Kelton, and Stephen (2013) to explore highly pathogenic avian influenza (HPAI), which covered poultry, bird health, animal disease, emerging infectious diseases, and the Canadian government's role as distinct from commercial producers. The study revealed that Canadian HPAI control policies (e.g., preemptive culling) were not well-aligned with stakeholders' views that government should keep people informed about the location of infections, report cases, and provide information on self-quarantining (Burns et al., 2013).

Surveys to three stakeholder groups (public, farmers, veterinarians) allowed Zingg and Siegrist (2012) to explore RP differences between experts and lay people, as well as gender effects, on animal epidemics, vaccination, culling, and RC. The authors found expert-lay person as well as gender differences, such that veterinarians reported lower risk and higher acceptance than the public did, while farmers had similar RP to the public. While vaccination was favored by all groups, RP differences were unrelated to knowledge (Zingg & Siegrist, 2012). A type E botulism disease outbreak case was informed by cultural models, RP, RC, SARF/risk attenuation, and comparison cases (Evensen, Decker, & Stedman, 2013). The authors found that while multiple factors influenced change in RP to a hazard, the most important were values, activities, management actions, visibility, and media coverage. Engaging various RC strategies at different times during a single hazard crisis as people's RP changed was recommended (Evensen et al., 2013).

Characteristics of a new risk were surveyed by Rudisill (2013) with respect to the H1N1 virus ("swine flu") to explore optimism, RP, risk classification, and prevention strategies. Intent to vaccinate was predicted by higher RP for H1N1 for self, avoiding others with flu-like symptoms, trust in the NHS, and having an at-risk condition (Rudisill, 2013). The extended parallel process model (EPPM) involving response efficacy and self-efficacy of preventive measures in response to threat was used by Klemm, Das, and Hartman (2015) to study the H1N1 pandemic, in which RC, RP, mass media dramatization, and risk amplification were key variables. It was determined that because all parties viewed the world from their unique position, objective risk reporting was not possible, and that the media may inadvertently have contributed to heightened RP through high volume coverage and bias toward the H1N1 threat (Klemm et al., 2015). Framing and scientific uncertainty formed the conceptual basis for an Australian media practices RC study of the swine flu pandemic in which the authors' thematic analysis was based on content analysis of media texts, and semi-structured interviews with experts (Holland, Blood, Imison, Chapman, & Fogerty, 2012). The main RC themes were "toeing the party line," which involved expert contributions to media coverage, and "playing the media game," which balanced objectives and identities (Holland et al., 2012).

Reviewing the prepandemic H5N1 ("bird flu") and SARS as emerging infectious disease (EID) case studies, Figuié (2014) considered a wide range of issues, including RR, political potential for risks, PP, and risk surveillance. Increasing interdependence between countries requires a paradigm shift from international management of threats to global RG, which also involves integrating multidisciplinary knowledge and acknowledging generational effects. The author drew attention to competition between WHO and the World Organization for Animal Health (OIE). Differing from threats in being uncertain, global, and anticipated catastrophes, risks require a paradigm of precaution, transparency, and participation. Legitimizing a wider scope for WHO and OIE in global RG was urged, with RG requiring a wide network, including scientific, lay, and administrative actors for appropriate political responses to EIDs. The case was presented as a risk society example of reframing toward instrumentalized global RG (Figuié, 2014).

The CERC (macro and micro phases) model and SARF were used in a case study workshop of pneumonic plague deaths, in which RC protocols, risk attenuation, crisis communication, and managing uncertainty emerged as key issues (Rickard, McComas, Clarke, Stedman, & Decker, 2013). RM strategies recommended were to build alliances and cooperation with key stakeholders precrisis to scan for emergent crises (CERC), ensure that structures are in place to respond to crises (i.e., plan), and employ post-crisis efforts to rebuild confidence (Rickard et al., 2013). Adopting the IRGC framework (simple, complex, uncertain, ambiguous risks) to assess infectious diseases, Roodenrijs, Kraaij-Dirkzwager, van den Kerkhof, and Runhaar (2014) examined RG, disease control, and outcome criteria (effectiveness, acceptance) in the comparative case study of Q-fever (Q = Query) and SBV. IRGC elements include preassessment, appraisal, characterization and evaluation, management, and communication. Roodenrijs et al. (2014) recommended incorporating concern assessment for ambiguous risks (e.g., Q-fever epidemic) but not for uncertain risks (e.g., SBV outbreak) and warned of the danger of unnecessary actions (e.g., RAs). Gathering interview data to study zoonotic disease, Busby and Duckett (2012) recommended using SARF and attribution theory to "correct" wrong impressions. From a six-wave longitudinal survey ranking risks, Brady (2012) identified RPs for a range of risks, including terrorism/war, accidents, crime, illness, environmental and natural disasters, as well as disease. As RP increased for each period studied Brady (2012) obtained a good model fit for infectious diseases and natural disasters.

While not a pandemic threat, a public health poisoning case from Panama involving RC, crisis communication, fear appeals, and threat provided Turner, Boudewyns, Kirby-Straker, and Telfer (2013) with the opportunity to content analyze news coverage and government information. Using EPPM (components: severity, susceptibility, response-efficacy, self-efficacy) and social cognitive theory, the authors noted that risk and crisis messages must adequately communicate the threat and steps to avert it. Threat response combined threat appraisal with efficacy appraisal. The news media tended to emphasize threat over avoidance strategies, while government information was better as it was more balanced, which was important or people would otherwise seek to control their fear rather than address the threat effectively (Turner et al., 2013).

11.5.3 General health issues

While none of the other WEF societal risk categories were represented by papers within the sample, papers addressing general health issues are reviewed here. Specific health risks were addressed in a few papers. A Singapore-based telephone survey explored RP of breast cancer risk, including influences of mass media, intention, interpersonal communication, knowledge, fatalistic beliefs, elaboration, and preventive measures (Lee, Ho, Chow, Wu, & Yang, 2013). The resultant model revealed the best predictors of behavioral intent to be knowledge, frequency of communication, elaboration, and RP. RP was predicted by media attention, fatalistic beliefs, knowledge structure density, and communication frequency. Media use was advocated to increase RP and behavioral intent (e.g., for screening), and for leveraging interpersonal communication (Lee et al., 2013).

A large dataset allowed Yan and Brocksen (2013) to model adolescents' RP for binge drinking, substance use, and smoking. High RP was associated with low substance use likelihood in high schoolers, and was positively associated with higher educational attainment (Yan & Brocksen, 2013). Another U.S. survey used health belief model and protection motivation theory variables (worry, affect, perceived vulnerability, behavioral intent, exercise) to model RP for diabetes (Portnoy, Kaufman, Klein, Doyle, & de Groot, 2014). The authors cautioned that when assessing RP not to conflate independent effects of cognitive and affective perceived vulnerability as they may have interactive effects (Portnoy et al., 2014). Mental models were also used in a study of lay perceptions of scientific information on noncompliance risk of statin use for high blood cholesterol

(Chakraborty, 2013a). Multiple factors affected patient noncompliance, the most common being a poor doctor–patient relationship. While trust was highly value-based, social distrust in specific health care system actors also led to high noncompliance risk (Chakraborty, 2013a). In a follow-up study, the author found high overall distrust in the health care system, and particularly in government, drug companies, the Federal Drug Administration (FDA), and FDA/industry relationships. To increase compliance, the author urged developing a social contract with patients, addressing distrust elements, and basing RC on RP (Chakraborty, 2013b). Cameron's illness risk representation framework (identity, cause, timeline, consequences, control) was the conceptual basis for a UK survey of chlamydia risk from casual sex, including likelihood, severity, underlying beliefs, intentions, and RA (Newby, French, Brown, & Wallace, 2013). The authors identified a need to isolate beliefs for targeting health promotion interventions and developing condom use skills (Newby et al., 2013).

A French focus group endocrine disrupter controversy, involving uncertainty, RP, RC, male fertility, emotions (fear, guilt, powerlessness, fatalism, optimism, relief, outrage, confusion), responsibility, and control by Maxim, Mansier, and Grabar (2013) reviewed the Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters in communicating uncertainty, value and risk framing. It was revealed that lay people raised more and different uncertainties than researchers did, and that reactions to different sources of uncertainty differed (i.e., were not global). While people accepted scientific uncertainty, it generated confusion, particularly if associated with an inability to identify and control risk origins. The authors argued for augmenting traditional probabilistic RAs (e.g., for chemicals) with qualitative RAs incorporating uncertainty (Maxim et al., 2013). A Dutch survey on electromagnetic field risk considered trust, RP, control, government policy, and risk response (van Dongen, Claassen, Smid, & Timmermans, 2013). In the authors' model, RP mediated trust and risk response, with control as a moderator. If perceived control was low, then lack of trust in government policy may enhance health RP, and increase risk response (van Dongen et al., 2013). From a U.S. online survey on information seeking on vaccination that considered risk-as-feeling, trust, and affect, the authors recommended tailoring communication to increase individuals' intent to seek information about prevention (Catellier & Yang, 2012).

Using the value-based relational theory of risk (risk object, object at risk) to study antibacterial silver in health care and consumer products controversy, Swedish researchers analyzed texts to examine RC to stakeholders (Boholm, Arvidsson, Boholm, Corvellec, & Molander, 2015). While the agent had both risks and benefits, the authors identified 17 codes for objects at risk, and a further 17 codes for conflicting RC on risk objects (Boholm et al., 2015). A legal case analysis formed the backdrop for a Dutch study of new technology medical devices, referring to litigation, acceptable risk, RA, patient health, and liability (de Mol, 2014). A conceptual framework embedded in risk–benefit, ALARA, ALARP, and idea to implementation led the author to recommend a broadly-based RG framework for continuing to accept the need for criminal and civil litigation and class actions to adjust legislation and to realize regulatory compliance (de Mol, 2014). Medical GM biotechnology was the topic of Fleming, Townsend, van Hilten, Spence, and Ferguson's (2012) study, whose survey of anaesthetists and the public revealed differential RP ratings by experts and lay persons (biases and heuristics, particularly affect heuristic) who respectively adopted System 1 versus System 2 DM. Finding RP to be negatively correlated with perceived benefit, led the authors to recommend providing experts with an expertise-relevant context to reduce reliance on low-effort (System 1) heuristics (Fleming et al., 2012).

A biosecurity case study analysis of stakeholder involvement in import risk analysis regarding fire blight, reviewing impacts on risk mitigation, uncertainty, and international trade, led Wintle and Cleeland (2012) to consider broader effects on RG, the WTO, and legislation. It was noted that values and interests shaped interpretation of risks, while RA was for achieving other goals, not for reducing risk (Wintle & Cleeland, 2012). A study of water transport for medical services in Arkansas from modeling emergency response management calculated a waterway emergency medical service feasibility index (Nachtmann & Pohl, 2013). Modeled parameters were accessibility to navigable waterways, proximity to barge origin, population demands, social vulnerability, risk of disaster, and limited access to medical services (Nachtmann & Pohl, 2013).

A few papers used a health risk theme as a vehicle for exploring risk concepts and models more generically. Decision theory and decision strategy formed the framework for Sahlin and Hermerén (2012) to explore predictive and preventive medicine, individual autonomy, knowledge, personalized medicine, insurance, and fairness. The authors urged discussion before implementing personalized predictive and preventive medicine (Sahlin & Hermerén, 2012). A Canadian RP rating survey of 30 health hazards by experts and public samples, as well as revealing gender differences, found that experts perceived behavioral risks highest, and recommended that RC strategies should take account of public RPs (Krewski, Turner, Lemyre, & Lee, 2012). A U.S. survey of public meetings, and civic engagement on health issues revealed that views of public officials influenced public willingness to attend meetings (Besley, McComas, & Trumbo, 2012). A framework of risk information seeking was the basis for a Dutch study of health RP, behavioral adaptation, fear appeals, RC, and response efficacy (Kievik, ter Huurne, & Gutteling, 2012). The authors found that the high-involvement, high-risk perception, high-response efficacy group was most likely to seek information and to change behavior (Kievik et al., 2012).

Four papers under the health theme concerned aspects of the pharmaceutical industry. The EU Directive 2010/84/EU, other legislation, and company post-marketing reporting, led the Irish Medicines Board (2015) to consider RC, patient engagement, trust, information, vigilance, RA, and the risk–benefit balance. The view was extended that publishing raw data on adverse events of medicine use might not be appropriate as it may create doubt and concern rather than trust in protection afforded by regulation (Irish Medicines Board, 2015). Reviewing European drug safety regulation, transparency, RC, RP, public trust versus confusion, serious adverse reaction to drugs/medicines ("side effects"), risk amplification, and the role of medical practitioners, Löfstedt and Way (2015) noted that full disclosure ("fishbowl transparency") required explanation and context (e.g., raw data access). While more information did not necessarily lead to better DM, enhanced transparency required integration with effective science-based risk–benefit RC (Löfstedt & Way, 2015). Commenting on Löfstedt and Way (2015), and highlighting transparency, RC, side effects, and public concern, Miller (2015) urged greater medical transparency. In a further comment on Löfstedt and Way (2015), focusing on transparency, trust, IDs, and pharmaceutical sector public safety update reports, noting that trust related to different parties, Meijer (2015) asked whether too much trust was to be avoided, observing that transparency stimulated organizations to improve practices.

11.6 Technological

Only one paper from the sample specifically focused on any of the three WEF technological risk subheadings: Breakdown of critical information infrastructure and networks; Escalation in large-scale cyber attacks; and Massive incidents of data fraud/theft.

Reviewing 13 RM certification methodologies, from Taiwan Yang, Ku, and Liu (2015) tested an integrated system for information security management (ISISM). Describing software to represent a knowledge self-assessment model for business impact analysis, RA, and security requirement engineering, the authors reviewed 10 ISISM steps while incorporating features of several other approaches (Yang, Ku, et al., 2015). In addition, Levine (2012) used the context of a cyber attack on an information systems network to explore the effectiveness of risk matrices and risk rating systems as RA tools. A further paper from Iran addressed generic issues associated with critical infrastructure. Using risk analysis and management for critical asset protection (RAMCAP), RA, fuzzy set theory and rules, Alidoosti, Yazdani, Fouladgar, and Basiri (2012) modeled risk categories, uncertainty, fuzzy logic, threats, consequences, and vulnerability in a qualitative case study. The authors recommended using fuzzy sets when risk factors are imprecise (Alidoosti et al., 2012).

11.7 Risk governance and risk management

While all papers in the sample related to RM or RG, around 30 papers had some aspect of these as a prime focus, including elements of strategic RM, enterprise RM (ERM), regulation, political, or policy features. Two case studies of organizational risk concerned with ideological, organizational, and methodological mechanisms, were the basis of Huber and Rothstein's (2013) study of failure, involving ERM, government agencies (DEFRA, HEFCE), organizational sensitivity to impacts, RC, and reputation risk. The authors noted that risk-oriented organizations identified and accepted failure, and viewed RM practices as a conservative force of organizational continuity (Huber & Rothstein, 2013).

Four studies, from Denmark, New Zealand, South Korea, and the United Kingdom, respectively, addressed ERM and corporate risk issues. A pharmaceutical industry case was the basis for Jensen, Ponsaing, and Thrane (2012) risky business experimental simulation to examine structural risk (parallel interactions), risk events, cost of risk mechanisms, prioritization, value, projects, negotiations, and resources. Noting that ERM required risk resource forecasting, the authors identified four mitigation strategy types: capital requirements, risk diversification, insurance, and networking (Jensen et al., 2012). A water utility case was the topic of Donnelly, Clement, Le Heron, and St George's (2012) ERM review of subjective risk, risk frameworks (operations, project, strategic), risk register, RA, RC, uncertainty, prioritization, and the role of the CRO. In reviewing RM standards and risk knowledge as an emergent process, the authors observed that neither tailored nor one-size approaches could reconcile conflicting objectives in designing corporate risk frameworks. Stakeholder engagement enhanced CRO effectiveness (Donnelly et al., 2012).

The Korean Crisis Management Guideline of Public Organizations was the framework for Kim (2014) to adopt a mixed methods approach (content analysis, interviews, focus groups) to explore integrated and dispersed approaches to CM (prevention, preparedness, response, recovery), as well as self-regulation, internal control, and the CRO's role. The author argued for building integrated CM systems and introducing ERM processes, for which communication between government and organizations' CROs was critical in ensuring enforced self-regulation, with the audit department conducting secondary RM (Kim, 2014). Schiller and Prpich (2014) reviewed organizational learning, RC, risk–risk trade-offs, forms of integrative organizational RM, and incommensurability of risks. Reporting on ERM attempts to integrate and compare strategic, financial, hazard, and operational RM, the authors noted ERM shortcomings that included unknown interdependencies between risks, implementation strategies that lacked empirical validation, ambivalence, uncertainty, that it was weakly rooted in organizational theory, and that it reduced all RM to financial criteria (Schiller & Prpich, 2014).

Another five papers addressed risk governance (RG) issues, including strategic RM and social risk management (SRM). The IRGC framework formed the basis for the organizational RG case studies through which Boholm, Corvellec, and Karlsson (2012) studied DM, regulation, public transportation, river management, railway planning, and RG practice. RG observations included taking account of how actors mediated multilevel and regulatory institutional constraints, and solved problems via routines, trust, mutual understanding, and shared commitment to infrastructure (Boholm et al., 2012). The IRGC cyclic model was also the stage for Tavares and dos Santos' (2014) RG municipal level hazard analysis, involving, RC, local level appraisal, emergency planning, natural, technological and environmental hazards, and social vulnerability. The authors noted how national civil protection RM solutions could be adapted to build a local model from preassessment to emergency planning and DM stages centered on communication and citizen and stakeholder involvement (Tavares & dos Santos, 2014).

Assessing natural hazards through historical frequency-consequence variation led Bilusich, Lord, and Nunes-Vaz (2015) to adopt a strategic RM power laws approach to treatment prioritization, national security, DM, empirical data, and risk representation. To understand their relative contributions to total risk, it was essential to identify the entire distribution of event sizes and frequencies of both high and low consequence events (Bilusich et al., 2015). A disaster RM framework was used by Neisser (2014) to explore riskscapes, heterogeneity, agency, complexity, and RG. The author championed ANT as an analytical tool for disaster RM, planning, design, and DM (Neisser, 2014).

The risk problem comprising complexity, scientific uncertainty, and sociopolitical ambiguity, led Klinke and Renn (2012) to proselytize an adaptive and integrative RG decision tree framework that included expert, stakeholder, and public input. The authors argued that RG should go beyond traditional RA to include preestimation, interdisciplinary risk estimation, risk characterization and evaluation, RM, monitoring, and control, in a step-by-step procedure (Klinke & Renn, 2012). Within an SRM framework Asenova, Bailey, and McCann (2015) reviewed five local authority cases to address public sector spending cuts, risk mitigation, and RG. The lack of an SRM DM model to manage cuts, and protect vulnerable groups required an extensive role for RM in RG structures (Asenova et al., 2015). Development of a new RM tool, the CDRM, using an engineering, construction and procurement sector case, was promoted by Arena et al. (2013). Advocating strategic integrated/holistic RM, involving dynamic capabilities, project-based organization, and risk and opportunity breakdown structure, the authors stressed the need to take account of the level at which risks are managed, either project, function, portfolio, or enterprise, and integrating capabilities at each level. Event responses included delivery, learning, integration/coordination, reconfiguration, unevenness, and polarization (Arena et al., 2013).

Economic analysis and effective risk allocation was the framework for a case study of construction, childcare, and operating risk in 11 kindergartens (Mouraviev & Kakabadse, 2014). Eleven risk types were identified including PPP risks, DM, high demand from non-core services, ERM, RG, regulatory risk, and political risk. The considerable revenue risk was of government transfer of nearly all risk to the private partner. The risk imbalance implied a need for a better RG structure for risk allocation. The authors recommended allocating risks to ensure clear assignment of parties' responsibilities, streamlined financing schemes, and incentives to complete projects on time. Partners should share demand risk and project default risk. In principle, risk should be transferred to the party best able to manage it in the most cost-effective manner (Mouraviev & Kakabadse, 2014).

Four papers focused on RR and compliance issues. The GMO Bt-11 maize case study involving testing current regulation against future events was considered by Drott et al. (2013) within the RG context of uncertain risks, supranational governance (EU), slow DM, political dynamics, and piecemeal accountability. An RA frame involving risk producers, risk assessors, and risk managers, led the authors to advocate the necessity of accountability as a prerequisite for legitimacy. Uncertain risks posed particular RG challenges, so that overall accountability might remain problematic as blame shifting could lead to organizational irresponsibility (Drott et al., 2013). An augmented IRGC model provided the framework for Naime and Andrey (2013) to examine hazardous installations, land-use planning/controls, risk-informed regulation, DM, complex systems, PP, vulnerability, and resilience. Urging a resilience plan based on a better transition between RA and RM, the authors advocated specific RM routines for exposure to technological hazards, and a more complete RM tool for integration with land-use planning RM (Naime & Andrey, 2013).

The Dutch national Risk and Responsibility Program was the framework for van Tol's (2015) survey of public attitudes to safety, expectations about government role, incidents, media role in RP, deregulation, and EU legislation. Noting that while the public tended to scope moral values when deciding on risk acceptability, government tended to limit RR policy to risk reduction, the author argued that government should tune in to public attitudes toward risk. Because moral acceptability of risk is more important than its size, public acceptance hinged on moral reasons for taking risks (van Tol, 2015). From Mexico, an experimental approach explored risk-aversion measures in estimating risks and benefits of different actions (Revollo-Fernandez & Aguilar-Ibarra, 2014). Studying regulation compliance within a framework of natural common pool resources (e.g., fisheries), individual versus collective benefits, free-riding, and sustainability, it was revealed that women were more risk averse and less selfish than men were. Introducing two new risk-aversion measures—risk-elasticity of extraction, and noncompliance risk index, the authors found that 60% enforcement probability led to higher extraction than did 20% and 40% enforcement conditions. In seeking to determine the optimal level of enforcement, it was found that external regulation (e.g., fines) was less effective than co-management (Revollo-Fernandez & Aguilar-Ibarra, 2014).

11.8 Conclusions

The three categories of systemic risk addressed in WEF (2014) were (1) sociopolitical instability increasing global inequalities; (2) challenges facing youth—particularly education costs, frustrated career aspirations, un/employment, debt, economic insecurity, and distrust of traditional political institutions; and (3) a breakdown of trust in the Internet—"digital disintegration" as the dynamic between attackers and defenders plays out within a context of hyper-connectivity. The last of these threats is an indication of how rapidly human society, particularly risk-aware youth, becomes highly dependent upon what in historical terms is a very recent technology. The WEF report also reinforced the notion that global systemic risks are not amenable to purely technical solutions. The role of complex transport systems has the potential to spread risks (e.g., disease pandemics like Ebola) rapidly and globally, while the rise of chronic conditions such as diabetes is projected to advance in nearly all countries, in some cases massively over the next two decades, with inevitable pressure on health care costs. To increase global resilience to the increasing complexity and interdependence of systemic risks, simpler and flexible rather than evermore complex regulatory frameworks are required (WEF, 2014). As noted by this report: ". . . the agile and the adaptable are most likely to thrive" (p. 33).

Global risks are becoming more center stage in risk-related debates (Huang, 2012). Society is becoming increasingly risk averse (Beck, 1992), perhaps because of the greater visibility of risks and communications about them, as well as phenomena such as risk amplification and systems implications of events or issues identified as risks. There is continuing divergence between populations and authorities with respect to RP and RM priorities (Mudu & Beck, 2012). Three current trends in risk research identified by these authors were (1) increased adoption of multidisciplinary approaches; (2) the problematic distinction between risk proximity and distance; and (3) the socially constructed and multiscalar definitions of key terms (e.g., risk, danger, vulnerability) across various dimensions. The nature of risk is changing, for example, becoming more focused on risks associated with developing technologies and entangled with emotional responses to risk, such as worry and fear (Räsänen et al., 2012).

Increasingly, risks are "boundaryless" insofar as while a certain type of risk might be deemed to "inhabit" a particular location or environment, the complexity of contemporary systems inevitably means that organizations or domains cannot remain isolated, but are best represented as a series of overlapping subsystems. For example, because many people drive as a major component of their work, road traffic risks overlap with occupational risks, as do multiple risks encountered by employees in their daily lives, including potentially stressful and anxiety-creating encounters with significant others, including family members. To survive and thrive, organizations need to take account of increasing complexity in their business and operational environments, inter alia, including political, social, environmental, financial, ethical, and communication factors. Thus, for an organization RM needs to be envisaged as a complex tapestry in which these various threads are woven. Reflecting this complexity, the risk and RM literature has become increasingly diverse in terms of context, methodology, and subject matter. Now, nearly all disciplines and professions embrace risk concepts and have their own perspective on what constitutes "risk management." For this reason, RM insights are likely to be gleaned from a broad spectrum of research and practice.

Discussion of risk, particularly within the academic research literature, has become increasingly conceptual. On the one hand, this reflects the dimensional complexity of this multifaceted and problematic concept. On the other hand, it is frequently difficult to derive usable generic RM/RG strategies from published studies. As noted by the WEF (2014), ". . . traditional concepts of risk have become inappropriate as a basis of modern global governance" (p. 27). There needs, inter alia, to be a greater synergy between risk researchers and practitioners (e.g., business leaders, politicians). The researcher–practitioner divide has been observed in other disciplines (e.g., organizational psychology), and efforts seeking to bridge this divide often founder on the fundamentally different motivations of the two main parties, which in turn are driven by their respective employment and personal agendas as well as by their separate agency relationships to the concrete representation of the risks about which they write or have to deal with. Among the best examples of such a divide in the risk domain is the debate on widespread devastating effects of anthropogenic climate change, in which many political agents continue to ignore the overwhelming scientific evidence, illustrating the lack of ability and willingness of political leaders to address risks that will play out beyond their immediate term (WEF, 2014).

At a macro level, the task of building capacity to address the global complexities of RM/RG, including risk–risk trade-offs, can seem overwhelming when expressed in words (e.g., Jovanović & Pileć, 2013; WEF, 2014). That RM is not a panacea for progress or even a route to the diminution of risks, was highlighted by Huber and Rothstein (2013), who observed that ". . . consultants, public inquiries and organizational scholars that optimistically see risk management as the solution to the deeply organizational roots of accidents and disasters are likely to be disappointed if further thought is not given to the organizational roots of risk management itself" (p. 671).

Possible existential or catastrophic risks identified by the WEF (2014) included significant na-tech events, as yet unknown risks from emerging sciences (e.g., nanotechnology, viruses created by synthetic biology, artificial intelligence), antibiotic-resistant bacteria, solar super storms devastating communications networks, self-perpetuating climate change after reaching a tipping point, and meteorite or asteroid strike. All such risks require global cooperation to prepare for their possible worst effects and to mitigate their potential for harm. From the literature reviewed in this chapter, some general conclusions emerge.

1. Risk researchers have mainly focused on dramatic, acute, and fairly obvious threats, rather than the "slow burn" variety, which being less evident and of low drama quality (e.g., biodiversity loss), are much less likely to be addressed in the risk literature, but rather are topics of investigation and report in relevant specialized scientific journals.
2. A repeating theme is the criticality of participant and multiple stakeholder involvement and engagement in risk decision making, and in risk management and risk governance issues more broadly. Trust or the lack of trust, in government agencies, scientists, and other experts, were common threads in many of the papers reviewed. It is becoming increasingly axiomatic that affected publics should have a genuine voice in the risks that they are exposed to. A basis for such engagement might be the principles of procedural justice, for example, as extemporized by Rawls (2001).
3. Closely aligned with what was stated earlier is that risk communication needs to become increasingly two-way, so that rather than being seen as "experts" delivering information to the lay public, RC can reciprocate public worries and fears to risk governance agencies. Where information needs to be delivered to the public, then it should be tailored to groups to take adequate account, inter alia, of differences in culture, values, and group differences in message receptiveness.
4. While some cases have developed "celebrity status" as anchors for many risk-related debates, for example, Bhopal, Piper Alpha, Three Mile Island, Chernobyl, and Fukushima, risk–risk trade-offs have become an increasingly common feature of risk debates. While on the one hand this reflects the global interdependency and ubiquitous nature of risks, it also suggests that individuals have only so much available capacity for personal risk appraisal and are only able to deal with a limited number of risk issues at any one time. This might at least in part account for a dominance of high salience, acute, and dramatic threats (e.g., terrorism) over hard-to-detect, chronic, and more confusing (e.g., climate change) risks. These phenomena might also indicate that, at least for individuals, risk–risk trade-offs equate to risk attenuation. Akin to the finite-pool-of-worry hypothesis (Nakayachi et al., 2015), a person's limited capacity to juggle a limited number of risks at any one time inevitably means that those that have been dropped, or are out of sight, have effectively been attenuated.
5. Reflecting the global reach of many contemporary risks (e.g., disease pandemics, terrorism, financial system collapse, web-based cyber attacks) attempts to address risks on a global scale, for example, through a variety of agencies such as the UN, ICAO, OIE, WHO, WEF, ILO, G20, IRGC, and ISO, are increasing. It remains to be determined whether such international agencies will broadly succeed in their efforts to manage the complexity of contemporaneous global risks effectively.

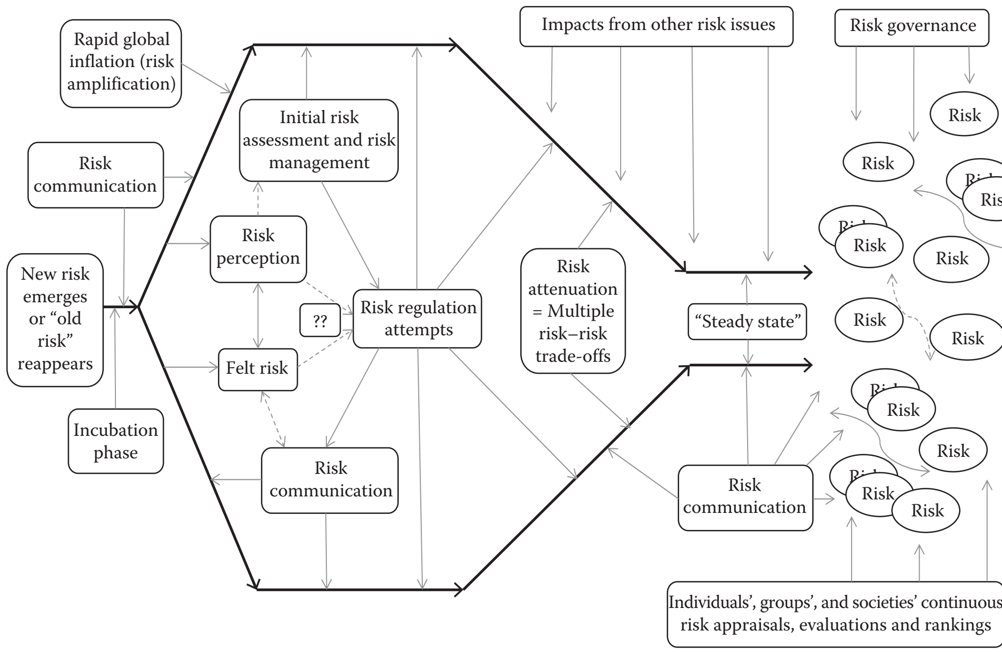


Figure 11.1 The risk universe.

6. The complexity of risk issues has been reflected in the plethora of sophisticated risk assessment methodologies, models, and statistical procedures that continue to emerge. Particularly post-2000, we have entered the era of high-risk expertise. Organizations increasingly seek to incorporate all potential sources of risk within their RM portfolios to enhance business survival and success, so that KPIs are commonly aligned with safety (and perhaps also environmental) performance indicators.
7. A considerable diversity, almost a profusion, of conceptual frameworks and methodologies is available for the study of risk. This reflects the complexity and multidimensional nature of risk concepts, for which mixed methods and triangulated approaches are needed to enhance our understanding of how to analyze and manage threats to human and ecological system viability. It also represents the diversity of disciplinary contributions to the study of risk. The multiplicity of acronyms to an extent reflects this conceptual and disciplinary diversity, and a number of these make multiple appearances within the literature particularly: risk management (RM—management, business, organizational contributions), risk perception (RP—cognitive psychology), risk communication (RC—sociology, media studies), risk assessment (RA—hard science, engineering, technology), risk regulation (RR—sociolegal), and risk governance (RG—political). A picture of the relationships between these concepts is shown in Figure 11.1.

References

Abelkop, A. D. K., & Graham, J. D. (2014). Comment: Principles and tools of chemical regulation: A comment on 'the substitution principle in chemical regulation: A constructive critique'. *Journal of Risk Research*, *17*(5), 581–586. doi:10.1080/13669877.2013.841742

Åberg, L., Larsen, L., Glad, A., & Beilinson, L. (1997). Observed vehicle speed and drivers' perceived speed of others. *Applied Psychology*, *46*(3), 235–247. doi:10.1111/j.1464-0597.1997.tb01231.x

Aberra, Y. (2012). Perceptions of climate change among members of the House of Peoples' Representatives, Ethiopia. *Journal of Risk Research*, *15*(7), 771–785. doi:10.1080/13669877.2012.657219

Ackerman, D. (1990). *A natural history of the senses.* New York, NY: Vintage Books.

Adelstein, A. M. (1952). Accident proneness: A criticism of the concept based upon an analysis of shunters' accidents. *Journal of the Royal Statistical Society*, *115*(3), 354–410.

Adie, W., Cairns, J., Macdiarmid, Ross, J., Watt, S., Taylor, C. L., & Osman, L. M. (2005). Safety culture and accident risk control: Perceptions of professional divers and offshore workers. *Safety Science*, *43*(2), 131–145. doi:10.1016/j.ssci.2005.01.003

Adkins, J. A., Quick, J. C., & Moe, K. O. (2000). Building world-class performance in changing times. In L. R. Murphy & C. L. Cooper (Eds.), *Healthy and productive work: An international perspective* (pp. 107–131). London, UK: Taylor & Francis.

Adolphs, R. (2004). Processing of emotional and social information by the human amygdala. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1017–1030). Cambridge, MA: MIT Press.

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In J. Kuhl & J. Beckman (Eds.), *Action–control: From cognition to behavior* (pp. 11–39). Heidelberg, Germany: Springer.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179–211.

Albouy, P., Mattout, J., Bouet, R., Maby, E., Sanchez, G., Aguera, P-E., … Tillmann, B. (2013). Impaired pitch perception and memory in congenital amusia: The deficit starts in the auditory cortex. *Brain*, *136*(5), 1639–1661. doi:10.1093/brain/awt082

Alidoosti, A., Yazdani, M., Fouladgar, M. M., & Basiri, M. H. (2012). Risk assessment of critical asset using fuzzy inference system. *Risk Management: A Journal of Risk, Crisis and Disaster, 14*(1), 77–91. doi:10.1057/rm.2011.19

Allen, N. J., & Hecht, T. D. (2004). The "romance of teams": Toward an understanding of its psychological underpinnings and implications. *Journal of Occupational and Organizational Psychology*, *77*(4), 439–461. doi:10.1348/0963179042596469

Allison, L., & Jeka, J. J. (2004). Multisensory integration: Resolving ambiguities for human postural, control. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 785–797). Cambridge, MA: MIT Press.

Althaus, C. E. (2005). A disciplinary perspective on the epistemological status of risk. *Risk Analysis*, *25*(3), 567–588. doi:10.1111/j.1539-6924.2005.00625.x

Alvesson, M. (1993). *Cultural perspectives on organizations.* Cambridge, England: Cambridge University Press.

Alvesson, M. (2001). *Understanding organizational culture.* London, UK: Sage.
Alwan, A., MacLean, D. R., Riley, L. M., d'Espaignet, E. T., Mathers, C. D., Stevens, G. A., & Bettcher, D. (2010). Chronic diseases: Chronic diseases and development 5: Monitoring and surveillance of chronic non-communicable diseases: Progress and capacity in high-burden countries. *The Lancet*, *376*(9755), 1861–1868. doi:10.1016/S0140-6736(10)61853-3
Amunts, K., Lepage, C., Borgeat, L., Mohlberg, H., Dickscheid, T., Rousseau, M-É., … Evans, A. C. (2013, 21). BigBrain: An ultrahigh-resolution 3D human brain model. *Science*, *340*(6139), 1472–1475. doi:10.1126/science.1235381
Anastasio, T. J., & Patton, P. E. (2004). Analysis and modelling of multisensory enhancement in the deep superior colliculus. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 265–283). Cambridge, MA: MIT Press.
Ancione, G., Salzano, E., Maschio, G., & Milazzo, M. F. (2015). A GIS-based tool for the management of industrial accidents triggered by volcanic ash fallouts. *Journal of Risk Research*. doi:10.1080/13669877.2014.961515
Anders af Wåhlberg, A., & Dorn, L. (2009). Bus driver accident record: The return of accident proneness. *Theoretical Issues in Ergonomics Science*, *10*(1), 77–91. doi:10.1080/14639220801912597
Anderson, S. W., Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1999). Impairment of social and moral behavior related to early damage in human prefrontal cortex. *Nature Neuroscience*, *2*(11), 1032–1037. doi:10.1038/14833
Andreasen, N. C., & Black, D. W. (2001). *Introductory textbook of psychiatry* (3rd ed.). Washington, DC: American Psychiatric Publishing.
Anelli, F., Borghi, A. M., & Nicoletti, R. (2012). Grasping the pain: Motor resonance with dangerous affordances. *Consciousness and Cognition*, *21*(4), 1627–1639. doi:10.1016/j.concog.2012.09.001
Anelli, F., Nicoletti, R., Bolzani, R., & Borghi, A. M. (2013). Keep away from danger: Dangerous objects in dynamic and static situations. *Frontiers in Human Neuroscience*, *7*, 344. doi:10.3389/fnhum.2013.00344
Anelli, F., Nicoletti, R., Kalkan, S., Sahin, E., & Borghi, A. M. (2012). *Human and robotics hands grasping danger*. The 2012 International Joint Conference on Neural Networks (June 16–20, pp. 1613–1620). Manno-Lugano, Switzerland: IEEE.
Anelli, F., Ranzini, M., Nicoletti, R., & Borghi, A. M. (2013). Perceiving object dangerousness: An escape from pain? *Experimental Brain Research*, *228*(4), 457–466. doi:10.1007/s00221-013-3577-2
Antonakis, J., Avolio, B. J., & Sivasubramaniam, N. (2003). Context and leadership: An examination of the nine-factor full-range leadership theory using the Multifactor Leadership Questionnaire. *The Leadership Quarterly*, *14*(3), 261–295. doi:10.1016/S1048-9843(03)00030-4
Antonsen, S. (2009). Safety culture and the issue of power. *Safety Science*, *47*(2), 183–191. doi:10.1016/j.ssci.2008.02.004
Aporta, C., & Higgs, E. (2005). Satellite culture: Global positioning systems, Inuit wayfinding, and the need for a new account of technology. *Current Anthropology*, *46*(5), 729–753. doi:10.1086/432651
Applebaum, E., & Batt, R. (1994). *The new American workplace*. Ithaca, NY: ILR Press.
Arena, M., Azzone, G., Cagno, E., Ferretti, G., Prunotto, E., Silvestri, A., & Trucco, P. (2013). Integrated risk management through dynamic capabilities within project-based organizations: The company dynamic response map. *Risk Management: A Journal of Risk, Crisis and Disaster*, *15*(1), 50–77. doi:10.1057/rm.2012.12
Argilés, J. M. (2005). Cancer-associated malnutrition. *European Journal of Oncology Nursing*, *9*(Suppl. 2), S39–S50. doi:10.1016/j.ejon.2005.09.006
Armony, J. L., & LeDoux, J. E. (2000). How danger is encoded: Toward a systems, cellular, and computational understanding of cognitive-emotional interactions in fear. In M. S. Gazzanigna (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1067–1079). Cambridge, MA: MIT Press.
Arnett, J. J. (1990). Drunk driving, sensation seeking, and egocentrism among adolescents. *Personality and Individual Differences*, *11*(6), 541–546. doi:10.1016/0191-8869(90)90035-P
Arnett, J. J. (1994). Sensation seeking: A new conceptualization and a new scale. *Personality and Individual Differences*, *16*(2), 289–296. doi:10.1016/0191-8869(94)90165-1
Arnett, J. J., Offer, D., & Fine, M. A. (1997). Reckless driving in adolescence: State and trait factors. *Accident Analysis & Prevention*, *29*(1), 57–63. doi:10.1016/S0001-4575(97)87007-8

Arnold, J. A., Arad, S., Rhoades, J. A., Drasgow, F., & Wiley, J. (2000). The empowering leadership questionnaire: The construction and validation of a new scale for measuring leader behaviors. *Journal of Organizational Behavior*, *21*(3), 249–269. doi:10.2307/3100332

Arstila, V. (2012). Time slows down during accidents. *Frontiers in Psychology*, *3*, 196. doi:10.3389/fpsyg.2012.00196

Arthur, B., Barrett, G. V., & Alexander, R. A. (1991). Prediction of vehicular involvement: A meta-analysis. *Human Performance*, *4*(2), 89–105. doi:10.1207/s15327043hup0402_1

Arthur, W., & Doverspike, D. (2001). Predicting motor vehicle crash involvement from a personality measure and a driving knowledge test. *Journal of Prevention and Intervention in the Community*, *22*(1), 35–42. doi:10.1080/10852350109511209

Arthur, W., & Graziano, W. G. (1996). The five-factor model, conscientiousness, and driving accident involvement. *Journal of Personality*, *64*(3), 593–618. doi:10.1111/j.1467-6494.1996.tb00523.x

Arthur, W., Strong, M. H., & Williamson, J. (1994). Validation of a visual attention test as a predictor of driving accident involvement. *Journal of Occupational and Organizational Psychology*, *67*(2), 173–182. doi:10.1111/j.2044-8325.1994.tb00559.x

Arzy, S., Brezis, M., Khoury, S., Simon, S. R., & Ben-Hur, T. (2009). Misleading one detail: A preventable mode of diagnostic error? *Journal of Evaluation in Clinical Practice*, *15*(5), 804–806. doi:10.1111/j.1365-2753.2008.01098.x

Asaridou, S. S., & McQueen, J. M. (2013). Speech and music shape the listening brain: Evidence for shared domain-general mechanisms. *Frontiers in Psychology*, *4*, 321. doi:10.3389/fpsyg.2013.00321

Asenova, D., Bailey, S. J., & McCann, C. (2015). Public sector risk managers and spending cuts: Mitigating risks. *Journal of Risk Research*, *18*(5), 552–565.

Ash, J., & Smallman, C. (2003, September 15). *Dying without permission—Risk management during hazardous rescues, and the implications for public service modernization and delivery*. Paper presented at the British Academy of Management Conference, September 15–17, Harrogate, UK.

Aspell, J. E., Heydrich, L., Marillier, G., Lavanchy, T., Herbelin, B., & Blanke, O. (2013). Turning body and self inside out: Visualized heartbeats alter bodily self-consciousness and tactile perception. *Psychological Science*, *24*(12), 2445–2453. doi:10.1177/0956797613498395

Atak, A., & Kingma, S. (2011). Safety culture in an aircraft maintenance organisation: A view from the inside. *Safety Science*, *49*, 268–278. doi:10.1016/j.ssci.2010.08.007

Australian Transport Safety Bureau. (2013). *VFR flight into dark night involving Aérospatiale AS355F2 VH-NTV: 145 km north of Maree, South Australia, 18 August 2011* (ATSB Transport Safety Report AO-2011-102 Final). Canberra, ACT: ATSB.

Auvray, M., Myin, E., & Spence, C. (2010). The sensory-discriminative and affective-motivational processing of pain. *Neuroscience & Biobehavioral Reviews*, *34*(2), 214–223. doi:10.1016/j.neubiorev.2008.07.00

Auvray, M., & Spence, C. (2008). The multisensory perception of flavor. *Consciousness and Cognition*, *17*(3), 1016–1031. doi:10.1016/j.concog.2007.06.00

Aven, T. (2014). Comment: The substitution principle in chemical regulation: A constructive critique, by Ragnar Löfstedt. *Journal of Risk Research*, *17*(5), 569–571. doi:10.1080/13669877.2013.841738

Avolio, B. J. (1999). *Full leadership development: Building the vital forces in organizations.* Newbury Park, CA: Sage.

Avolio, B. J., & Gardner, W. L. (2005). Authentic leadership development: Getting to the root of positive forms of leadership. *The Leadership Quarterly*, *16*(3), 315–338. doi:10.1016/j.leaqua.2005.03.001

Avolio, B. J., Kroeck, K. G., & Panek, P. E. (1985). Individual differences in information-processing ability as a predictor of motor vehicle accidents. *Human Factors*, *27*(5), 577–587. doi:10.1177/001872088502700506

Avolio, B. J., Reichard, R. J., Hannah, S. T., Walumba, F. O., & Chan, A. (2009). A meta-analytic review of leadership impact research: Experimental and quasi-experimental studies. *The Leadership Quarterly*, *20*(5), 764–784. doi:10.1016/j.leaqua.2009.06.006

Axtell, C. M., Holman, D. J., Unsworth, K. L., Wall, T. D., Waterson, P. E., & Harrington, E. (2000). Shopfloor innovation: Facilitating the suggestion and implementation of ideas. *Journal of Occupational and Organizational Psychology*, *73*(3), 265–285. doi:10.1348/096317900167029

Ayuso, M., Bermúdez, L., & Santolino, M. (2012). Influence of parties' behavioural features on motor compensation disputes in insurance markets. *Journal of Risk Research*, *15*(6), 673–691. doi:10.1080/13669877.2011.652652

Baars, B. J. (2005). Global workspace theory of consciousness: Toward a cognitive neuroscience of human experience. *Progress in Brain Research*, *150*, 45–53. doi:10.1016/s0079-6123(05)50004-9

Bacon, L. P., & Strybel, T. Z. (2013). Assessment of the validity and intrusiveness of online-probe questions for situation awareness in a simulated air-traffic-management task with student air-traffic controllers. *Safety Science*, *56*, 89–95. doi:10.1016/j.ssci.2012.06.019

Bacon, L. P., Strybel, T. Z., Vu, K-P. L., Nguyen, J. H., Battiste, V., & Johnson, W. (2011). Situation awareness, workload, and performance in midterm NextGen: Effect of variations in aircraft equipage levels between scenarios. In *Proceedings of the 16th International Symposium on Aviation Psychology* (pp. 32–37). Dayton, OH.

Bagnara, S., Baldasseroni, A., Parlangeli, O., Taddei, S., & Tartaglia, R. (1999). Italy: A school of nursing. In M. Kompier & C. L. Cooper (Eds.), *Preventing stress, improving productivity: European case studies in the workplace* (pp. 297–311). London, UK: Routledge.

Bailes, H. J., & Lucas, R. J. (2013). Human melanopsin forms a pigment maximally sensitive to blue light (λ_{max}≈479 nm) supporting activation of $G_{q/11}$ and $G_{i/o}$ signalling cascades. *Proceedings of the Royal Society B: Biological Sciences*, *280*(1759), 20122987. doi:10.1098/rspb.2012.2987

Bailey, K., West, R., & Kuffel, J. (2013). What would my avatar do? Gaming, pathology, and risky decision making. *Frontiers in Psychology*, *4*, 609. doi:10.3389/fpsyg.2013.00609

Baldus, H., Klabunde, K., & Müsch, G. (2004). Reliable set-up of medical body-sensor networks. In H. Karl, A. Willig, & A. Wolisz (Eds.), *Wireless sensor networks* (pp. 353–363). Berlin/Heidelberg, Germany: Springer.

Baliki, M. N., Geha, P. Y., & Apkarian, A. V. (2009). Parsing pain perception between nociceptive representation and magnitude estimation. *Journal of Neurophysiology*, *101*(2), 875–887. doi:10.1152/jn.91100.2008

Ball, D. J., & Watt, J. (2013). The risk to the public of tree fall. *Journal of Risk Research*, *16*(2), 261–269. doi:10.1080/13669877.2012.737827

Ball, P. (2011). *The music instinct: How music works and why we can't do without it*. London, UK: Vintage Books.

Ball, S. A., & Zuckerman, M. (1992). Sensation seeking and selective attention: Focused and divided attention on a dichotic listening task. *Journal of Personality and Social Psychology*, *63*(5), 825–831. doi:10.1037/0022-3514.63.5.825

Balslev, D., Himmelbach, M., Karnath, H-O., Borchers, S., & Odoj, B. (2012). Eye proprioception used for visual localization only if in conflict with the oculomotor plan. *The Journal of Neuroscience*, *32*(25), 8569–8573. doi:10.1523/jneurosci.1488-12.2012

Bamberger, P., & Biron, M. (2007). Group norms and excessive absenteeism: The role of peer referent others. *Organizational Behavior and Human Decision Processes*, *103*(2), 179–196. doi:10.1016/j.obhdp.2007.03.003

Banbury, S., Dudfield, H., Hoerman, H., & Soll, H. (2007). FASA: Development and validation of a novel measure to assess the effectiveness of commercial airline pilot situation awareness training. *International Journal of Aviation Psychology*, *17*(2), 131–152. doi:10.1080/10508410701328557

Bandura, A. (1977). *Social learning theory*. Englewood Cliffs, NJ: Prentice Hall.

Bandura, A. (1989 April). *Self-efficacy in the exercise of control*. Paper presented to the Annual Conference of the British Psychological Society, St Andrews, UK.

Bang, H. N., & Few, R. (2012). Social risks and challenges in post-disaster resettlement: The case of Lake Nyos, Cameroon. *Journal of Risk Research*, *15*(9), 1141–1157. doi:10.1080/13669877.2012.705315

Banks, V. A., Stanton, N. A., & Harvey, C. (2014a). Sub-systems on the road to vehicle automation: Hands and feet free but not 'mind' free driving. *Safety Science*, *62*, 505–514. doi:10.1016/j.ssci.2013.10.014

Banks, V. A., Stanton, N. A., & Harvey, C. (2014b). What the drivers do and do not tell you: Using verbal protocol analysis to investigate driver behaviour in emergency situations. *Ergonomics*, *57*(3), 332–342. doi:10.1080/00140139.2014.884245

Baram, M. (2014). International workshop on liability and insurance and their influence on safety management of industrial operations and products. *Journal of Risk Research*, *17*(6), 683–687. doi:10.1080/13669877.2014.889196

Barbi, F., & da Costa Ferreira, L. (2014). Risks and political responses to climate change in Brazilian coastal cities. *Journal of Risk Research*, *17*(4), 485–503. doi:10.1080/13669877.2013.788548

Barling, A. J., Weber, T., & Kelloway, E. K. (1996). Effects of transformational leadership training on attitudinal and financial outcomes: A field experiment. *Journal of Applied Psychology*, *81*(6), 827–832. doi:10.1037/0021-9010.81.6.827

Barling, J., Christie, A., & Hoption, C. (2011). Leadership. In S. Zedeck (Ed.), *APA handbook of industrial and organizational psychology* (pp. 183–240). Washington, DC: American Psychological Association.

Barling, J., Kelloway, E. K., & Iverson, R. D. (2003). Accidental outcomes: Attitudinal consequences of workplace injuries. *Journal of Occupational Health Psychology*, *8*(1), 74–85. doi:10.1037/1076-8998.8.1.74

Barling, J., Loughlin, C., & Kelloway, E. K. (2000). *Development and test of a model linking transformational leadership and occupational safety*. Paper presented at the Annual Conference of the Society for Industrial and Organizational Psychology, New Orleans, LA.

Barling, J., Loughlin, C., & Kelloway, E. K. (2002). Development and test of a model linking safety-specific transformational leadership and occupational safety. *Journal of Applied Psychology*, *87*(3), 488–496. doi:10.1037/0021-9010.87.3.488

Baron, R. A. (2002). *Essentials of psychology* (3rd ed.). Needham Heights, MA: Allyn & Bacon.

Barrett, D. (2013). One surveillance camera for every 11 people in Britain, says CCTV survey. *The Telegraph*, July 10, 2013. http://www.telegraph.co.uk/technology/10172298/One-surveillance-camera-for-every-11-people-in-Britainsays-CCTV-survey.html. Accessed June 24, 2015.

Barrick, M. R., & Mount, M. K. (1991). The big five personality dimensions and job performance: A meta-analysis. *Personnel Psychology*, *44*(1), 1–26. doi:10.1111/j.1744-6570.1991.tb00688.x

Barry, R. J. (2009). Habituation of the orienting reflex and the development of preliminary process theory. *Neurobiology of Learning and Memory*, *92*(2), 235–242. doi:10.1016/j.nlm.2008.07.007

Barry, R. J., MacDonald, B., De Blasio, F. M., & Steiner, G. Z. (2013). Linking components of event-related potentials and autonomic measures of the orienting reflex. *International Journal of Psychophysiology*, *89*(3), 366–373. doi:10.1016/j.ijpsycho.2013.01.016

Basbaum, A. I., Bushnell, M. C., Smith, D. V., Beauchamp, G. K., Firestein, S. J., Dallos, P., … Kaas, J. H. (Eds.). (2008). *The senses: A comprehensive reference* (Vol. 6). London, UK: Academic Press.

Bass, B. M. (1985). *Leadership and performance beyond expectations*. New York, NY: Free Press.

Bass, B. M. (1997). Does the transactional–transformational leadership paradigm transcend organizational and national boundaries? *American Psychologist*, *52*(2), 130–139. doi:10.1037/0003-066X.52.2.130

Bass, B. M. (1998). *Transformational leadership: Industrial, military and educational impact*. Mahwah, NJ: Erlbaum.

Bass, B. M., & Steidlmeier, P. (1999). Ethics, character, and authentic transformational leadership behavior. *The Leadership Quarterly*, *10*(2), 181–217. doi:10.1016/S1048-9843(99)00016-8

Bate, P. (1984). The impact of organizational culture on approaches to organizational problem solving. *Organizational Studies*, *5*(1), 43–66. doi:10.1177/017084068400500103

Baublyte, L., Mullins, M., & Garvey, J. (2012). Risk selection in the London political risk insurance market: The role of tacit knowledge, trust and heuristics. *Journal of Risk Research*, *15*(9), 1001–1116. doi:10.1080/13669877.2012.705312

Bauer, T. N., & Green, S. G. (1996). Development of leader-member exchange: A longitudinal test. *The Academy of Management Journal*, *39*(6), 1538–1567. doi:10.2307/257068

Bavelier, D., & Hirshorn, E. A. (2010). I see where you're hearing: How cross-modal plasticity may exploit homologous brain structures. *Nature Neuroscience*, *13*(11), 1309–1311. doi:10.1038/nn1110-1309

Beauchamp, M. S. (2005). See me, hear me, touch me: Multisensory integration in lateral occipital-temporal cortex. *Current Opinion in Neurobiology*, *15*(2), 145–153. doi:10.1016/j.conb.2005.03.011

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, *275*(5304), 1293–1295. doi:10.1126/science.275.5304.1293

Beck, A. T., Emery, G., & Greenberg, B. L. (1985). *Anxiety, disorders, and phobias: A cognitive perspective*. New York, NY: Basic Books.

Beck, E., André-Poyard, I., Davoine, P.-A., Chardonnel, S., & Lutoff, C. (2012). Risk perception and social vulnerability to earthquakes in Grenoble (French Alps). *Journal of Risk Research*, *15*(10), 1245–1260. doi:10.1080/13669877.2012.652649

Beck, M., & Wolfson, C. (1999). Safety culture: A concept too many? *The Health and Safety Practitioner*, *16*(1), 14–16.

Beck, U. (1992). *Risk society: Towards a new modernity*. London, UK: Sage.

Beehr, T. (1998). An organizational psychology meta-model of occupational stress. In C. L. Cooper (Ed.), *Theories of organizational stress* (pp. 6–27). New York, NY: Oxford University Press.

Beehr, T. A., & Bowling, N. A. (2005). Hardy personality, stress, and health. In C. L. Cooper (Ed.), *Handbook of stress medicine and health* (2nd ed., pp. 193–211). London, UK: CRC Press.

Beer, J. S., Shimamura, A. P., & Knight, R. T. (2004). Frontal lobe contributions to executive control of cognitive and social behavior. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1091–1104). Cambridge, MA: MIT Press.

Begg, D., & Langley, J. (2001). Changes in risky driving behavior from age 21 to 26 years. *Journal of Safety Research*, *32*(4), 491–499. doi:10.1016/S0022-4375(01)00059-7

Behnam, B., Skitmore, M., & Ronagh, H. R. (2015). Risk mitigation of post-earthquake fire in urban buildings. *Journal of Risk Research*, *18*(5), 602–621. doi:10.1080/13669877.2014.910686

Beirness, D. J. (1993). Do we really drive as we live? The role of personality factors in road crashes. *Alcohol, Drugs and Driving*, *9*(3–4), 129–143.

Bell, C., Bourke, C., Colhoun, H., Carter, F., Frampton, C., & Porter, R. (2011). The misclassification of facial expressions in generalised social phobia. *Journal of Anxiety Disorders*, *25*(2), 278–283. doi:10.1016/j.janxdis.2010.10.001

Benavides, F. G., Benach, J., Diez-Roux, A. V., & Roman, C. (2000). How do types of employment relate to health indicators? Findings from the second European survey on working conditions. *Journal of Epidemiology Community Health*, *54*(7), 494–501. doi:10.1136/jech.54.7.494

Benet-Martínez, V., & John, O. P. (1998). Los Cinco Grandes across cultures and ethnic groups: Multitrait-multidimensional analyses of the Big Five in Spanish and English. *Journal of Personality and Social Psychology*, *75*(3), 729–750. doi:10.1037/0022-3514.75.3.729

Benet-Martínez, V., & John, O. P. (2000). Toward the development of quasi-indigenous personality constructs: Measuring Los Cinco Grandes in Spain with indigenous Castillian markers. *American Behavioral Scientist*, *44*(1), 141–157. doi:10.1177/00027642000044001011

Benet-Martínez, V., & Waller, N. G. (1997). Further evidence for the cross-cultural generality of the Big Seven factor model: Indigenous and imported Spanish personality constructs. *Journal of Personality*, *65*(3), 567–598. doi:10.1111/j.1467-6494.1997.tb00327.x

Bennett, E. L., Milner-Gulland, E. J., Bakarr, M., Eves, H. E., Robinson J. G., & Wilkie, D. S. (2002). Hunting the world's wildlife to extinction. *Oryx*, *36*(4), 328–329. doi:10.1017/S0030605302000637

Bensafi, M., Zelano, C., Johnson, B., Mainland, J., Khan, R., & Sobel, N. (2004). Olfaction: From sniff to percept. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 259–280). Cambridge, MA: MIT Press.

Bentata, P. (2014). On the joint use of safety regulation and civil liability to promote safe management of hazardous operations: A French case study. *Journal of Risk Research*, *17*(6), 721–734. doi:10.1080/13669877.2014.889198

Berger, A., Tzur, G., & Posner, M. I. (2006). Infant brains detect arithmetic errors. *Proceedings of the National Academy of Sciences*, *103*(33), 12649–12653. doi:10.1073/pnas.0605350103

Bernhardt, B. C., & Singer, T. (2012). The neural basis of empathy. *Annual Review of Neuroscience*, *35*, 1–23. doi:10.1146/annurev-neuro-062111-150536

Besley, J. C., & McComas, K. A. (2015). Something old and something new: Comparing views about nanotechnology and nuclear energy. *Journal of Risk Research*, *18*(2), 215–213. doi:10.1080/13669877.2014.896397

Besley, J. C., McComas, K. A., & Trumbo, C. W. (2012). Citizen views about public meetings. *Journal of Risk Research*, *15*(4), 355–371. doi:10.1080/13669877.2011.634516

Beullens, K., Roe, K., & Van den Bulck, J. (2008). Video games and adolescents' intentions to take risks in traffic. *Journal of Adolescent Health*, *43*(1), 87–90. doi:10.1016/j.jadohealth.2007.12.002

Beullens, K., Roe, K., & Van den Bulck, J. (2011). Excellent gamer, excellent driver? The impact of adolescents' video game playing on driving behavior: A two-wave panel study. *Accident Analysis and Prevention*, *43*(1), 58–65. doi:10.1016/j.aap.2010.07.011

Beus, J. M., Dhanani, L. Y., & McCord, M. A. (2015). A meta-analysis of personality and workplace safety: Addressing unanswered questions. *Journal of Applied Psychology*, *100*(2), 481–498. doi:10.1037/a0037916

Beus, J. M., Payne, S. C., Bergman, M. E., & Arthur, W. (2010). Safety climate and injuries: An examination of theoretical and empirical relationships. *Journal of Applied Psychology*, *95*(4), 713–727. doi:10.1037/a0019164

Bharate, S. S., & Bharate, S. B. (2012). Modulation of thermoreceptor TRPM8 by cooling compounds. *ACS Chemical Neuroscience*, *3*(4), 248–267. doi:10.1021/cn300006u

Białek, M., & Sawicki, P. (2014). Can taking the perspective of an expert debias human decisions? The case of risky and delayed gains. *Frontiers in Psychology*, *5*, 989. doi:10.3389/fpsyg.2014.00989

Bidelman, G. M. (2013). The role of the auditory brainstem in processing musically relevant pitch. *Frontiers in Psychology*, *4*, 264. doi:10.3389/fpsyg.2013.00264

Bierly, P. E., & Spender, J. C. (1995). Culture and high reliability organizations: The case of the nuclear submarine. *Journal of Management*, *21*(4), 639–656. doi:10.1177/014920639502100403

Billings, A. G., & Moos, R. H. (1984). Coping, stress, and social resources among adults with unipolar depression. *Journal of Personality and Social Psychology*, *46*(4), 877–891. doi:10.1037/0022-3514.46.4.877

Bilusich, D., Lord, S., & Nunes-Vaz, R. (2015). The implications of empirical data for risk. *Journal of Risk Research*, *18*(4), 521–538. doi:10.1080/13669877.2014.910682

Bindemann, M., Brown, C., Koyas, T., & Russ, A. (2012). Individual differences in face identification predict eyewitness accuracy. *Journal of Applied Research in Memory and Cognition*, *1*(2), 96–103. doi:10.1016/j.jarmac.2012.02.001

Birdi, K., Clegg, C., Patterson, M., Robinson, A., Stride, C. B., Wall, T. D., & Wood, S. J. (2008). The impact of human resource and operational management practices on company productivity: A longitudinal study. *Personnel Psychology*, *61*(3), 467–501. doi:10.1111/j.1744-6570.2008.00136.x

Biron, M., & Bamberger, P. (2012). Aversive workplace conditions and absenteeism: Taking referent group norms and supervisor support into account. *Journal of Applied Psychology*, *97*(4), 901–912. doi:10.1037/a0027437

Bisson, J. I., Ehlers, A., Matthews, R., Pilling, S., Richards, D., & Turner, S. (2007). Psychological treatments for chronic post-traumatic stress disorder. *British Journal of Psychiatry*, *190*(2), 97–104. doi:10.1192/bjp.bp.106.021402

Blanchard, C., Roll, R., Roll, J-P., & Kavounoudias, A. (2013). Differential contributions of vision, touch and muscle proprioception to the coding of hand movements. *PLoS One*, *8*(4), e62475. doi:10.1371/journal.pone.0062475

Blanchard, D. C., Griebel, G., Pobbe, R., & Blanchard, R. J. (2011). Risk assessment as an evolved threat detection and analysis process. *Neuroscience & Biobehavioral Reviews*, *35*(4), 991–998. doi:10.1016/j.neubiorev.2010.10.016

Blau, G. (1993). Testing the relationship of locus of control to different performance dimensions. *Journal of Occupational and Organizational Psychology*, *66*(2), 125–138. doi:10.1111/j.2044-8325.1993.tb00522.x

Blau, P. M. (1960). A theory of social integration. *American Journal of Sociology*, *65*(6), 545–556.

Blazsin, H., & Guldenmund, F. (2015). The social construction of safety: Comparing three realities. *Safety Science*, *71*(A), 16–27. doi:10.1016/j.ssci.2014.06.001

Blickensderfer, E., Cannon–Bowers, J. A., & Salas, E. (1998). Cross–training and team performance. In J. A. Cannon–Bowers & E. Salas (Eds.), *Making decisions under stress: Implications for individual and team training* (pp. 299–311). Washington, DC: American Psychological Association.

Blinkhorn, S., & Johnson, C. (1990). The significance of personality testing. *Nature*, *348*(6303), 671–672. doi:10.1038/348671a0

Blumenfeld, S. (2013). Location of hazardous materials plants in Israel. *Journal of Risk Research*, *16*(7), 921–935. doi:10.1080/13669877.2012.761269

Bohil, C. J., Higgins, N. A., & Keebler, J. R. (2014). Predicting and interpreting identification errors in military vehicle training using multidimensional scaling. *Ergonomics*, *57*(6), 844–855. doi:10.1080/00140139.2014.899631

Böhmer, M. (2012). A sense of touch. In M. Böhmer (Eds.), *Beginning Android ADK with Arduino* (Chapter 8). Berkeley, CA: Apress.

Boholm, A., Corvellec, H., & Karlsson, M. (2012). The practice of risk governance: Lessons from the field. *Journal of Risk Research*, *15*(1), 1–20. doi:10.1080/13669877.2011.587886

Boholm, M. (2013). The representation of nano as a risk in Swedish news media coverage. *Journal of Risk Research*, *16*(2), 227–244. doi:10.1080/13669877.2012.726243

Boholm, M., Arvidsson, R., Boholm, Å., Corvellec, H., & Molander, S. (2015). Dis-Agreement: The construction and negotiation of risk in the Swedish controversy over antibacterial silver. *Journal of Risk Research*, *18*(1), 93–110. doi:10.1080/13669877.2013.879492

Bojanowski, V., Hummel, T., & Croy, I. (2013). Isolated congenital anosmia—Clinical and daily life aspects of a life without a sense of smell. *Laryngo-rhino-otologie*, *92*(1), 30–33. doi:10.1055/s-0032-1329949

Bolger, N., & Zuckerman, A. (1995). A framework for studying personality in the stress process. *Journal of Personality and Social Psychology*, *69*(5), 890–902. doi:10.1037/0022-3514.69.5.890

Bond, F. W., & Bunce, D. (2001). Job control mediates change in a work reorganization intervention for stress reduction. *Journal of Occupational Health Psychology*, *6*(4), 290–302. doi:10.1037/1076-8998.6.4.290

Bonnet, E., Amalric, M., Chevé, M., & Travers, M. (2012). Hazard and living environment: Combining industrial risk and landscape representations. *Journal of Risk Research*, *15*(10), 1281–1298. doi:10.1080/13669877.2012.646289

Bor, D. (2012). *The ravenous brain: How the new science of consciousness explains our insatiable search for meaning*. New York, NY: Basic Books.

Borg, V., Kristensen, T. S., & Burr, H. (2000). Work environment and changes in self-rated health: A five year follow-up study. *Stress Medicine*, *16*(1), 37–47.

Borgersen, H. C., Hystad, S. W., Larsson, G., & Eid, J. (2014). Authentic leadership and safety climate among seafarers. *Journal of Leadership & Organizational Studies*, *21*(4), 394–402. doi:10.1177/1548051813499612

Bortner, R. (1969). A short rating scale as a potential measure of pattern A behavior. *Journal of Chronic Diseases*, *22*(2), 87–91. doi:10.1016/0021-9681(69)90061-7

Bosma, H., Stansfeld, S. A., & Marmot, M. G. (1998). Job control, personal characteristics, and heart disease. *Journal of Occupational Health Psychology*, *3*(4), 402–409. doi:10.1037/1076-8998.3.4.402

Bostrom, A. (2015). Progress in risk communication since the 1989 NRC report: Response to 'Four questions for risk communication' by Roger Kasperson. *Journal of Risk Research*, *17*(10), 1259–1264. doi:10.1080/13669877.2014.923032

Boudreau, C. E., & Ferster, D. (2004). Mechanisms of image processing in the visual cortex. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 303–312). Cambridge, MA: MIT Press.

Boyle, A. J. (1980). 'Found experiments' in accident research: Report of a study of accident rates and implications for further research. *Journal of Occupational Psychology*, *53*(1), 53–64. doi:10.1111/j.2044-8325.1980.tb00006.x

Bozek, F., Bumbova, A., Bakos, E., Bozek, A., & Dvorak, J. (2015). Semiquantitative risk assessment of groundwater resources for emergency water supply. *Journal of Risk Research*, *18*(4), 505–520. doi:10.1080/13669877.2014.910680

Braams, B. R., van Leijenhorst, L., & Crone, E. A. (2014). Risks, rewards, and the developing brain in childhood and adolescence. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 73–91). Washington, DC: American Psychological Association. doi:10.1037/14322-004

Bradley, B. H., Postlethwaite, B. E., Klotz, A. C., Hamdani, M. R., & Brown, K. G. (2012). Reaping the benefits of task conflict in teams: The critical role of team psychological safety climate. *Journal of Applied Psychology*, *97*(1), 151–158. doi:10.1037/a0024200

Bradley, G. L. (2007). Job tenure as a moderator of stressor-strain relations: A comparison of experienced and new-start teachers. *Work & Stress*, *21*(1), 48–64. doi:10.1080/02678370701264685

Bradley, G. L. (2010). Work-induced changes in feelings of mastery. *Journal of Psychology: Interdisciplinary and Applied*, *144*(2), 97–119. doi:10.1080/00223980903472128

Bradley, G. L., Reser, J. P., Glendon, A. I., & Ellul, M. C. (2014). Distress and coping in response to climate change. In K. Kaniasty, K. A. Moore, S. Howard, & P. Buchwald (Eds.), *Stress and anxiety: Applications to social and environmental threats, psychological well-being, occupational challenges, and developmental psychology* (pp. 33–42). Berlin, Germany: Logos.

Bradley, G. L., & Wildman, K. (2002). Psychosocial predictors of emerging adults' risk and reckless behaviors. *Journal of Youth and Adolescence*, *31*(4), 253–265. doi:10.1023/A:1015441300026

Bradley, M. M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology*, *46*(1), 1–11. doi:10.1111/j.1469-8986.2008.00702.x

Bradley, M. M., Lang, P. J., & Cuthbert, B. N. (1993). Emotion, novelty, and the startle reflex: Habituation in humans. *Behavioral Neuroscience*, *107*(6), 970–980. doi:10.1037/0735-7044.107.6.970

Brady, J. T. (2012). Health risk perceptions across time in the USA. *Journal of Risk Research*, *15*(6), 547–563. doi:10.1080/13669877.2011.643476

Brady, S. S. (2006). Lifetime community violence exposure and health risk behavior among young adults in college. *Journal of Adolescent Health*, *39*(4), 610–613. doi:10.1016/j.jadohealth.2006.03.007

Brand, C. R., & Egan, V. (1989). The 'big five' dimensions of personality? Evidence from ipsative, adjectival self-attributions. *Personality and Individual Differences*, *10*(11), 1165–1171. doi:10.1016/0191-8869(89)90080-9

Brandt, U. S. (2014). The implication of extreme events on policy responses. *Journal of Risk Research*, *17*(2), 221–240. doi:10.1080/13669877.2013.794151

Brazova, V. K., Matczak, P., & Takacs, V. (2015). Evolution of civil security systems: The case of three Central European countries. *Journal of Risk Research*, *18*(6), 789–806. doi:10.1080/13669877.2014.913659

Breedveld, L. (2013). Combining LCA and RA for the integrated risk management of emerging technologies. *Journal of Risk Research*, *16*(3–4), 459–468. doi:10.1080/13669877.2012.729526

Breiter, H. C., & Gasic, G. P. (2004). A general circuitry processing reward/aversion information and its implications for neuropsychiatric illness. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1043–1065). Cambridge, MA: MIT Press.

Bremner, A. J., Lewkowicz, D. J., & Spence, C. (2012). (Eds.). *Multisensory development*. Oxford, UK: Oxford University Press.

Bridger, R. S., Pisula, P., & Bennett, A. (2012). *A guide to understanding human factors and human behaviour in safety management and accident investigation*. Gosport, UK: Institute of Naval Medicine.

Brief, A. P., & George, J. M. (1995). Psychological stress and the workplace: A brief comment on Lazarus' outlook. In R. Crandall & P. L. Perrewé (Eds.), *Occupational stress: A handbook* (pp. 15–20). Washington, DC: Taylor & Francis.

Briner, R. B., & Reynolds, S. (1993). Bad theory and bad practice in occupational stress. *The Occupational Psychologist*, *19*, 8–13.

British Standards Institute. (2008). *Guide to evaluation of human exposure to vibration in buildings: Vibration sources other than blasting.* (BS 6472-1). London, UK: BSI.

Broadbent, D., Cooper, P., Fitzgerald, P., & Parkes, K. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology*, *21*(1), 1–16. doi:10.1111/j.2044-8260.1982.tb01421.x

Broadbent, D. E., Broadbent, M. H. P., & Jones, J. L. (1986). Performance correlates of self-reported cognitive failure and of obsessionality. *British Journal of Clinical Psychology*, *25*(4), 285–299. doi:10.1111/j.2044-8260.1986.tb00708.x

Broadbent, D. E., & Gath, D. (1981 March). Ill-health on the line: Sorting out myth from fact. *Employment Gazette*, March, 157–160.

Brodsky, W., & Slor, Z. (2013). Background music as a risk factor for distraction among young-novice drivers. *Accident Analysis and Prevention*, *59*, 382–393. doi:10.1016/j.aap.2013.06.022

Bröer, C., Moerman, G., Spruijt, P., & van Poll, R. (2014). Risk policies and risk perceptions: A comparative study of environmental health risk policy and perception in six European countries. *Journal of Risk Research*, *17*(4), 525–542. doi:10.1080/13669877.2014.889197

Brondino, M., Silva, S. A., & Pasini, M. (2012). Multilevel approach to organizational and group safety climate and safety performance: Co-workers as the missing link. *Safety Science*, *50*(9), 1847–1856. doi:10.1016/j.ssci.2012.04.010

Brooks, B. (2008). The natural selection of organizational and safety culture within a small to medium sized enterprise (SME). *Journal of Safety Research*, *39*(1), 73–85. doi:10.1016/j.jsr.2007.09.008

Brotheridge, C. M., & Lee, R. T. (2002). Testing a conservation of resources model of the dynamics of emotional labor. *Journal of Occupational Health Psychology*, *7*(1), 57–67. doi:10.1037/1076-8998.7.1.57

Brown, H. I. (2008). The case for indirect realism. In E. Wright (Ed.), *The case for qualia* (pp. 45–58). Cambridge, MA: MIT Press.

Brown, I. D. (1990). Drivers' margins of safety considered as a focus for research on error. *Ergonomics*, *33*(10–11), 1307–1314. doi:10.1080/00140139008925334

Brown, K., & Ryan, R. (2003). The benefits of being present: The role of mindfulness in psychological well-being. *Journal of Personality and Social Psychology*, *84*(4), 822–848. doi:10.1037/0022-3514.84.4.822

Brown, K. A., Willis, P. G., & Prussia, G. E. (2000). Predicting safe employee behavior in the steel industry: Development and test of a sociotechnical model. *Journal of Operations Management*, *18*(4), 445–465.

Brown, M. E., & Treviño, L. K. (2006). Ethical leadership: A review and future directions. *The Leadership Quarterly*, *17*(6), 595–616. doi:10.1016/j.leaqua.2006.10.004

Brown, M. E., Treviño, L. K., & Harrison, D. A. (2005). Ethical leadership: A social learning perspective for construct development and testing. *Organizational Behavior and Human Decision Processes*, *97*(2), 117–134. doi:10.1016/j.obhdp.2005.03.002

Brown, R. H. (2005). The sampling of gases and vapours: Principles and methods. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 208–221). Oxford, UK: Blackwell.

Brown, R. L., & Holmes, H. (1986). The use of factor–analytic procedure for assessing the validity of an employee safety climate model. *Accident Analysis and Prevention*, *18*(6), 455–470.

Bruder, G. E., Stewart, J. W., Mercier, M. A., Agosti, V., Leite, P., Donovan, S., & Quitkin, F. M. (1997). Outcome of cognitive–behavioural therapy for depression: Relation to hemispheric dominance for verbal processing. *Journal of Abnormal Psychology*, *106*(1), 138–144. doi:10.1037/0021-843X.106.1.138

Brulin, G., & Nilsson, T. (1994). *Arbetsutveckling och forbattract producktvitet (Development of work and improved productivity)*. Stockholm, Sweden: Arbetslivfonden.

Bruzzone, S. (2015). Risk forecast as work practice: Between codified and practical knowledge. *Journal of Risk Research*, *18*(2), 170–181. doi:10.1080/13669877.2014.889192

Bryden, R., & Hudson, P. T. K. (2005). *Safety and Health Practitioner*, *23*, 51–54.

Buckner, R. L., & Schacter, D. L. (2004). Neural correlates of memory's successes and sins. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 739–752). Cambridge, MA: MIT Press.

Bufalari, I., & Ionta, S. (2013). The social and personality neuroscience of empathy for pain and touch. *Frontiers in Human Neuroscience*, *7*, 393. doi:10.3389/fnhum.2013.00393

Burger, J. (2012a). Selenimum:mercury molar ratios in fish from the Savannah River: Implications for risk management. *Journal of Risk Research*, *15*(6), 627–644. doi:10.1080/13669877.2011.649298

Burger, J. (2012b). Rating of worry about energy sources with respect to public health, environmental health, and workers. *Journal of Risk Research*, *15*(9), 1159–1169. doi:10.1080/13669877.2012.705316

Burger, J. (2013). Role of self-caught fish in total fish consumption rates for recreational fishermen: Average consumption for some species exceeds allowable intake. *Journal of Risk Research*, *16*(8), 1057–1075. doi:10.1080/13669877.2013.788546

Burger, J., & Gochfeld, M. (2015). Concerns and perceptions immediately following Superstorm Sandy: Ratings for property damage were higher than for health issues. *Journal of Risk Research*, *18*(2), 249–265. doi:10.1080/13669877.2014.896401

Burger, J., Gochfeld, M., Jeitner, C., Donio, M., & Pittfield, T. (2014a). Sushi consumption rates and mercury levels in sushi: Ethnic and demographic differences in exposure. *Journal of Risk Research*, *17*(8), 981–997. doi:10.1080/13669877.2013.822925

Burger, J., Gocheld, M., Powers, C. W., Kosson, D., Clarke, J., & Brown, K. (2014b). Mercury at Oak Ridge: Outcomes from risk evaluations can differ depending upon objectives and methodologies. *Journal of Risk Research*, *17*(9), 1109–1124. doi:10.1080/13669877.2013.841731

Burke, R. J. (1993). Organizational-level interventions to reduce occupational stressors. *Work & Stress*, *7*(1), 77–87. doi:10.1080/02678379308257051

Burke, R. J., & Fiksenbaum, L. (2008). Work hours, work intensity and work addiction: Costs and benefits. In R. J. Burke & C. L. Cooper (Eds.), *The long work hours culture* (pp. 3–36). Bingley, UK: Emerald Group.

Burnham, J. C. (2008). The syndrome of accident proneness (Unfallneigung): Why psychiatrists did not adopt and medicalize it. *History of Psychiatry*, *19*(3), 251–274. doi:10.1177/0957154X07077594

Burns, C., Mearns, K., & McGeorge, P. (2006). Explicit and implicit trust within safety culture. *Risk Analysis*, *26*(5), 1139–1150. doi:10.1111/j.1539-6924.2006.00821.x

Burns, P. C., & Wilde, G. J. S. (1995). Risk taking in male taxi drivers: Relationships among personality, observational data and driver records. *Personality and Individual Differences*, *18*(2), 267–278. doi:10.1016/0191-8869(94)00150-Q

Burns, T. E., Ribble, C., McLaws, M., Kelton, D., & Stephen, C. (2013). Perspectives of an underrepresented stakeholder group, backyard flock owners, on poultry health and avian influenza control. *Journal of Risk Research*, *16*(2), 245–260. doi:10.1080/13669877.2012.726244

Burt, C. D. B., Gladstone, K. L., & Grieve, K. R. (1998). Development of the considerate and responsible employee (CARE) scale. *Work & Stress*, *12*(4), 362–369. doi:10.1080/02678379808256873

Burt, C. D. B., Sepie, B., & McFadden, G. (2008). The development of a considerate and responsible safety attitude in work teams. *Safety Science*, *46*(1), 79–91. doi:10.1016/j.ssci.2006.10.005

Burton, A. M., White, D., & McNeill, A. (2010). The Glasgow face matching test. *Behavior Research Methods*, *42*(1), 286–291. doi:10.3758/BRM.42.1.286

Busby, J. S., Alcock, R. E., & MacGillivray, B. H. (2012). Types of risk transformation: A case study. *Journal of Risk Research*, *15*(1), 67–84. doi:10.1080/13669877.2011.601324

Busby, J. S., & Duckett, D. (2012). Social risk amplification as an attribution: The case of zoonotic disease outbreaks. *Journal of Risk Research*, *15*(9), 1049–1074. doi:10.1080/13669877.2012.670130

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*(6), 215–222. doi:10.1016/S1364-6613(00)01483-2

Buss, A. T., Fox, N., Boas, D. A., & Spencer, J. P. (2013). Probing the early development of visual working memory capacity with functional near-infrared spectroscopy. *NeuroImage*, *85*, 314–325. doi:10.1016/j.neuroimage.2013.05.034

Buzsáki, G., & Moser, E. I. (2013). Memory, navigation and theta rhythm in the hippocampal-entorhinal system. *Nature Neuroscience*, *16*(2), 130–138. doi:10.1038/nn.3304

Cabinet Office. (2012). *Applying behavioural insights to reduce fraud, error and debt*. London, UK: Behavioural Insights Team.

Cai, Z., Richards, D. G., Lenhardt, M. L., & Madsen, A. G. (2002). Response of human skull to bone-conducted sound in the audiometric-ultrasonic range. *The International Tinnitus Journal*, *8*(1), 3–8.

Calvert, G. A. C., & Lewis, J. W. (2004). Hemodynamic studies of audiovisual interactions. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 483–502). Cambridge, MA: MIT Press.

Calvert, G. A. C., Spence, C., & Stein, B. E. (Eds.). (2004). *The handbook of multisensory processes*. Cambridge, MA: MIT Press.

Cameron, C., DiValentin, L., Manaktala, R., McElhaney, A., Nostrand, C., Quinlan, O., … Gerling, G. J. (2011). *Using electroactive polymers to simulate the sense of light touch and vibration in a virtual reality environment* (pp. 121–126). Hoboken, NJ: Systems Engineering Research Center, Institute of Electrical and Electronics Engineers.

Campbell, S. S. (1992). Effects of sleep and circadian rhythms on performance. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance, Vol. 3: State and trait* (pp. 195–216). London, UK: Academic Press.

Cannon–Bowers, J. A., Salas, E., Blickensderfer, E., & Bowers, C. A. (1998). The impact of cross–training and workload on team functioning: A replication and extension of initial findings. *Human Factors*, *40*(1), 92–101. doi:10.1518/001872098779480550

Cantor, D. W., Boyce, T. E., & Repetti, R. L. (2004). Ensuring healthy working lives. In R. H. Rozensky, N. G. Johnson, C. D. Goodheart, & W. R. Hammond (Eds.), *Psychology builds a healthy world: Opportunities for research and practice* (pp. 275–296). Washington, DC: American Psychological Association.

Carandini, M. (2004). Receptive fields and suppressive fields in the early visual system. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 313–326). Cambridge, MA: MIT Press.

Carhart-Harris, R. L., Leech, R., Hellyer, P. J., Shanahan, M., Feilding, A., Tagliazucchi, E., … Nutt, D. (2014). The entropic brain: A theory of conscious states informed by neuroimaging research with psychedelic drugs. *Frontiers in Human Neuroscience*, *8*, 20. doi:10.3389/fnhum.2014.00020

Carr, J. Z., Schmidt, A. M., Ford, J. K., & DeShon, R. P. (2003). Climate perceptions matter: A meta-analytic path analysis relating molar climate, cognitive and affective states, and individual level work outcomes. *Journal of Applied Psychology*, *88*(4), 605–619. doi:10.1037/0021-9010.88.4.605

Carson, J. B., Tesluk, P. E., & Marrone, J. A. (2007). Shared leadership in teams: An investigation of antecedent conditions and performance. *Academy of Management Journal*, *50*(5), 1217–1234. doi:10.2307/AMJ.2007.20159921

Carstensen, E. L., Buettner, A., Genberg, V. L., & Miller, M. W. (1985). Sensitivity of the human eye to power frequency electric fields. *IEEE Transactions on Biomedical Engineering*, *32*(8), 561–565.

Carstensen, L. L. (2006). The influence of a sense of time on human development. *Science*, *312*(5782), 1913–1915. doi:10.1126/science.1127488

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science*, *280*(5364), 747–749. doi:10.1126/science.280.5364.747

Carter, F. A., & Corlett, E. N. (1981). *Shiftwork and accidents*. Dublin, Ireland: European Foundation for the Improvement of Living and Working Conditions.

Cartwright, S., Cooper, C. L., & Barron, A. (1996). The company car driver: Occupational stress as a predictor of motor vehicle accident involvement. *Human Relations*, *49*(2), 195–208. doi:10.1177/001872679604900204

Cartwright, S., Cooper, C. L., & Whatmore, L. (2000). Improving communications and health in a government department. In L. R. Murphy & C. L. Cooper (Eds.), *Healthy and productive work: An international perspective* (pp. 67–82). London, UK: Taylor & Francis.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology*, *67*(2), 319–333. doi:10.1037/0022-3514.67.2.319

Casey, T. W., & Krauss, A. D. (2013). The role of effective error management practices in increasing miners' safety performance. *Safety Science*, *60*, 131–141. doi:10.1016/j.ssci.2013.07.001

Casey-Campbell, M., & Martens, M. L. (2009). Sticking it all together: A critical assessment of the group cohesion–performance literature. *International Journal of Management Reviews*, *11*(2), 223–246. doi:10.1111/j.1468-2370.2008.00239.x

Casillas, A., Robbins, S., McKinniss, T., Postlethwaite, B., & Oh, I. (2009). Using narrow facets of an integrity test to predict safety: A test validation study. *International Journal of Selection and Assessment*, *17*(1), 119–125. doi:10.1111/j.1468-2389.2009.00456.x

Caspi, C. E., Dennerlein, J. T., Kenwood, C., Stoddard, A. M., Hopcia, K., Hashimoto, D., & Sorensen, G. (2013). Results of a pilot intervention to improve health and safety for health-care workers. *Journal of Occupational and Environmental Medicine*, *55*(12), 1449–1455. doi:10.1097/JOM.0b013e3182a7e65a

Cassotti, M., Habib, M., Poirel, N., Aïte, A., Houdé, O., & Moutier, S. (2012). Positive emotional context eliminates the framing effect in decision-making. *Emotion*, *12*(5), 926–931. doi:10.1037/a0026788

Castellà, J., & Pèrez, J. (2004). Sensitivity to punishment and sensitivity to reward and traffic violations. *Accident Analysis & Prevention*, *36*(6), 947–952. doi:10.1016/j.aap.2003.10.003

Catchpole, K. (2013a). Spreading human factors expertise in healthcare: Untangling the knots in people and systems. *BMJ Quality & Safety*, *22*(10), 793–797. doi:10.1136/bmjqs-2013-002036

Catchpole, K. (2013b). Toward the modelling of safety violations in healthcare systems. *BMJ Quality & Safety*, *22*(9), 705–709. doi:10.1136/bmjqs-2012-001604

Catellier, J. R. A., & Yang, Z. J. (2012). Trust and affect: How do they impact risk information seeking in a health context? *Journal of Risk Research*, *15*(8), 897–911. doi:10.1080/13669877.2012.686048

Cavanaugh, M. A., Boswell, W. R., Roehling, M. V., & Boudreau, J. W. (2000). An empirical examination of self-reported work stress among US managers. *Journal of Applied Psychology*, *85*(1), 65–74. doi:10.1037/0021-9010.85.1.65

Cellar, D. F., Nelson, Z. C., York, C. M., & Bauer, C. (2001). The five-factor model and safety in the workplace: Investigating the relationships between personality and accident involvement. *Journal of Prevention and Intervention in the Community*, *22*(1), 43–52. doi:10.1080/10852350109511210

Cellar, D. F., Yorke, C. M., Nelson, Z. C., & Carroll, K. A. (2004). Relationships between five factor personality variables, workplace accidents, and self-efficacy. *Psychological Reports*, *94*(3c), 1437–1441. doi:10.2466/pr0.94.3c.1437-1441

Chadwick, P. (2005). Non-ionizing radiation: Electromagnetic fields and optical radiation. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 307–327). Oxford, UK: Blackwell.

Chakraborty, S. (2013a). Part I: The role of trust in patient noncompliance: A qualitative case study of users of statins for the chronic treatment of high-cholesterol in New York City. *Journal of Risk Research*, *16*(1), 97–112. doi:10.1080/13669877.2012.727097

Chakraborty, S. (2013b). Part II: The role of trust in patient noncompliance: A quantitative case study of users of statins for the chronic treatment of high cholesterol in New York City. *Journal of Risk Research*, *16*(1), 113–129. doi:10.1080/13669877.2012.727098

Chanda, M. L., & Levitin, D. J. (2013). The neurochemistry of music. *Trends in Cognitive Sciences*, *17*(4), 179–193. doi:10.1016/j.tics.2013.02.007

Chandola, T., Brunner, E., & Marmot, M. (2006). Chronic stress at work and the metabolic syndrome: Prospective study. *British Medical Journal*, *332*(7540), 521–525. doi:10.1136/bmj.38693.435301.80

Chapman, J. (March, 1982). After the inspector's visit: When group loyalty made a mockery of accident prevention. *The Safety Representative*, 5.

Chebat, D. R., Rainville, C., Kupers, R., & Ptito, M. (2007). Tactile-'visual' acuity of the tongue in early blind individuals. *Neuroreport*, *18*(18), 1901–1904. doi:10.1097/WNR.0b013e3282f2a63

Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental Science*, *14*(2), F1–F10. doi:10.1111/j.1467-7687.2010.01035.x

Chen, C. V., Tang, Y., & Wang, S. (2009). Interdependence and organizational citizenship behavior: Exploring the mediating effect of group cohesion in multilevel analysis. *Journal of Psychology: Interdisciplinary and Applied*, *143*(6), 625–640. doi:10.1080/00223980903218273

Chen, J. L., Zatorre, R. J., & Penhune, V. B. (2006). Interactions between auditory and dorsal premotor cortex during synchronization to musical rhythms. *Neuroimage*, *32*(4), 1771–1781. doi:10.1016/j.neuroimage.2006.04.207

Cherrie, J. W. (2005). Dermal exposure assessment. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 389–399). Oxford, UK: Blackwell.

Cheung, F. M., Leung, K., Fan, R. M., Song, W. S., Zhang, J. X., & Zhang, J. P. (1996). Development of the chinese personality assessment inventory. *Journal of Cross-Cultural Psychology*, *27*(2), 181–199. doi:10.1177/0022022196272003

Cheyne, A., Cox, S., Oliver, A., & Tomás, J. M. (1998). Modelling safety climate in the prediction of levels of safety activity. *Work & Stress*, *12*(3), 255–271. doi:10.1080/02678379808256865

Chiaburu, D. S., & Harrison, D. A. (2008). Do peers make the place? Conceptual synthesis and meta-analysis of coworker effects on perceptions, attitudes, OCBs, and performance. *Journal of Applied Psychology*, *93*(5), 1082–1103. doi:10.1037/0021-9010.93.5.1082

Chong, C.-Y., & Kumar, S. P. (2003). Sensor networks: Evolution, opportunities, and challenges. *Proceedings of the IEEE*, *91*(8), 1247–1256. doi:10.1109/JPROC.2003.814918

Choudhry, R., Fang, D., & Mohamed, S. (2007). Developing a model of construction safety culture. *Journal of Management in Engineering*, *23*(4), 207–212. doi:10.1061/(ASCE)0742-597X(2007)23:4(207)

Chowdhury, N. (2014). Environmental risk regulation and the Indian Supreme Court: An exercise in de-formalization of the law? *Journal of Risk Research*, *17*(1), 61–80. doi:10.1080/13669877.2013.822918

Chowdhury, P. D., Haque, C. E., & Driedger, S. M. (2012). Public versus expert knowledge and perception of climate change-induced heat wave risk: A modified mental model approach. *Journal of Risk Research*, *15*(2), 149–168. doi:10.1080/13669877.2011.601319

Christian, M. S., Bradley, J. C., Wallace, J. C., & Burke, M. J. (2009). Workplace safety: A meta-analysis of the roles of person and situation factors. *Journal of Applied Psychology*, *94*(5), 1103–1127. doi:10.1037/a0016172

Chughtai, A. A. (2015). Creating safer workplaces: The role of ethical leadership. *Safety Science*, *73*, 92–98. doi:10.1016/j.ssci.2014.11.016

Chung, C. K., & Pennebaker, J. W. (2008). Revealing dimensions of thinking in open-ended self-descriptions: An automated meaning extraction method for natural language. *Journal of Research in Personality*, *42*(1), 96–132. doi:10.1016/j.jrp.2007.04.006

Chung, Y. S., & Wu, H. L. (2013). Effect of burnout on accident involvement in occupational drivers. *Transportation Research Record: Journal of the Transportation Research Board*, *2388*(1), 1–9. doi:10.3141/2388-01

Churchland, P. S. (2002). Self-representation in nervous systems. *Science*, *296*(5566), 308–310. doi:10.1126/science.1070564

Chute, R., & Weiner, E. L. (1995). Cockpit–cabin communication I: A tale of two cultures. International *Journal of Aviation Psychology*, *5*(3), 257–276. doi:10.1207/s15327108ijap0503_2

Cicognani, E., & Zani, B. (2015). Communication of health risks from exposure to depleted uranium (DU) in Italy: A case study. *Journal of Risk Research*, *18*(6), 771–788. doi:10.1080/13669877.2014.913657

Clark, L., Bechara, A., Damasio, H., Aitken, M. R., Sahakian, B. J., & Robbins, T. W. (2008). Differential effects of insular and ventromedial prefrontal cortex lesions on risky decision-making. *Brain*, *131*(5), 1311–1322. doi:10.1093/brain/awn066

Clarke, S. (1994). Violations at work: Implications for risk management. In A. Cheyne, S. Cox, & K. Irving (Eds.), *Proceedings of the Fourth Annual Conference on Safety and Well–Being at Work* (pp. 116–126). Loughborough: Centre for Hazard and Risk Management.

Clarke, S. (1999). Perceptions of organizational safety: Implications for the development of safety culture. *Journal of Organizational Behavior*, *20*(2), 185–198. doi:10.1002/199903.20.2

Clarke, S. (2000). Safety culture: Under–specified and overrated? *International Journal of Management Reviews*, *2*(1), 65–90. doi:10.1111/1468-2370.00031

Clarke, S. (2006). The relationship between safety climate and safety performance: A meta-analytic review. *Journal of Occupational Health Psychology*, *11*(4), 315–327. doi:10.1037/1076-8998.11.4.315

Clarke, S. (2010). An integrative model of safety climate: Linking psychological climate and work attitudes to individual safety outcomes using meta-analysis. *Journal of Occupational and Organizational Psychology*, *83*(3), 553–578. doi:10.1348/096317909X452122

Clarke, S. (2011). Accident proneness: Back in vogue? In R. J. Burke, S. Clarke, & C. L. Cooper (Eds.), *Occupational health and safety* (pp. 95–117). Farnham, UK: Gower.

Clarke, S. (2012). The effect of challenge and hindrance stressors on safety behavior and safety outcomes: A meta-analysis. *Journal of Occupational Health Psychology*, *17*(4), 387–397. doi:10.1037/a0029817

Clarke, S. (2013). Safety leadership: A meta-analytic review of transformational and transactional leadership styles as antecedents of safety behaviours. *Journal of Occupational and Organizational Psychology*, *86*(1), 22–49. doi:10.1111/j.2044-8325.2012.02064.x

Clarke, S., & Cooper, C. L. (2004). *Managing the risk of workplace stress: Health and safety hazards*. London, UK: Routledge.

Clarke, S., & Flitcroft, C. (2011). *The effectiveness of occupational health and safety training in the promotion of a positive OSH culture*. Leicester, UK: Institute of Occupational Safety and Health (IOSH).

Clarke, S., Guediri, S., & O'Connor, E. (2013). Creating a safe and healthy work environment: The latest thinking and research evidence. In C. L. Cooper & R. J. Burke (Eds.), *The fulfilling workplace: The organization's role in achieving individual and organizational health* (pp. 265–286). Farnham, UK: Gower.

Clarke, S., & Robertson, I. T. (2005). A meta-analytic review of the big five personality factors and accident involvement in occupational and non-occupational settings. *Journal of Occupational and Organizational Psychology*, *78*(3), 355–376. doi:10.1348/096317905X26183

Clarke, S., & Ward, K. (2006). The role of leader influence tactics and safety climate in engaging employee safety participation. *Risk Analysis*, *26*(5), 1175–1186. doi:10.1111/j.1539-6924.2006.00824.x

Classen, C. (2012). *The deepest sense: A cultural history of touch*. Urbana, IL: The University of Illinois Press.

Clayton, R. E. (2005). Ionizing radiation: Physics, measurement, biological effects and control. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 328–343). Oxford, UK: Blackwell.

Clément, R., & Jonah, B. A. (1984). Field dependence, sensation seeking and driving behaviour. *Personality and Individual Differences*, *5*(1), 87–93. doi:10.1016/0191-8869(84)90141-7

Coello, Y., Bourgeois, J., & Iachini, T. (2012). Embodied perception of reachable space: How do we manage threatening objects? *Cognitive Processing*, *13*(1), 131–135. doi:10.1007/s10339-012-0470-z

Cohen, A. (1977). Factors in successful occupational safety programs. *Journal of Safety Research*, *9*(4), 168–178.

Cohen, B., & Raphan, T. (2004). The physiology of the vestibuoocular reflex (VOR). In S. M. Highstein, R. T. Fay, & A. N. Popper (Eds.), *The vestibular system* (pp. 235–285). New York, NY: Springer.

Cohen, S., & Edwards, J. R. (1989). Personality characteristics as moderators of the relationship between stress and disorder. In R. W. J. Neufeld (Ed.), *Advances in the investigation of psychological stress* (pp. 235–283). Oxford, UK: Wiley.

Cohen, S., Tyrrell, D. A. J., & Smith, A. P. (1991). Psychological stress and susceptibility to the common cold. *The New England Journal of Medicine*, *325*(9), 606–612.

Cohen, S. G., & Ledford, G. E. (1994). The effectiveness of self–managing teams: A quasi–experiment. *Human Relations*, *47*(1), 13–43. doi:10.1177/001872679404700102

Cohen, Y. E., & Andersen, R. A. (2004). Multisensory representations of space in the posterior parietal cortex. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 463–479). Cambridge, MA: MIT Press.

Cole, S., Balcetis, E., & Dunning, D. (2013). Affective signals of threat increase perceived proximity. *Psychological Science*, *24*(1), 34–40. doi:10.1177/0956797612446953

Colenbrander, A. (1963). The influence of G-forces on the counter-rolling of the eye. *Opthalmologica*, *146*, 309–313.

Colligan, M. J., & Cohen, A. (2004). The role of training in promoting workplace safety and health. In J. Barling & M. R. Frone (Eds.), *The psychology of workplace safety* (pp. 223–248). Washington, DC: American Psychological Association.

Collinson, D. L. (1999). Surviving the rigs: Safety and surveillance on North Sea oil installations. *Organization Studies*, *20*(4), 579–600. doi:10.1177/0170840699204003

Colquitt, A., Scott, B. A., & LePine, J. A. (2007). Trust, trustworthiness, and trust propensity: A meta-analytic test of their unique relationships with risk taking and job performance. *Journal of Applied Psychology*, *92*(4), 909–927. doi:10.1037/0021-9010.92.4.909

Conchie, S. M. (2013). Transformational leadership, intrinsic motivation, and trust: A moderated-mediated model of workplace safety. *Journal of Occupational Health Psychology*, *18*(2), 198–210. doi:10.1037/a0031805

Conchie, S. M., & Donald, I. J. (2008). The functions and development of safety-specific trust and distrust. *Safety Science*, *46*(1), 92–103. doi:10.1016/j.ssci.2007.03.004

Conchie, S. M., & Donald, I. J. (2009). The moderating role of safety-specific trust on the relation between safety-specific leadership and safety citizenship behaviors. *Journal of Occupational Health Psychology*, *14*(2), 137–147. doi:10.1037/a0014247

Conchie, S. M., Taylor, P. J., & Charlton, A. (2011). Trust and distrust in safety leadership: Mirror reflections? *Safety Science*, *49*(8–9), 1208–1214. doi:10.1016/j.ssci.2011.04.002

Conchie, S. M., Taylor, P. J., & Donald, I. J. (2012). Promoting safety voice with safety-specific transformational leadership: The mediating role of two dimensions of trust. *Journal of Occupational Health Psychology*, *17*(1), 105–115. doi:10.1037/a0025101

Confederation of British Industry. (1990). *Developing a safety culture – Business for safety*. London, UK: Confederation of British Industry.

Confederation of British Industry (CBI). (1993). *Assessing the risk: Implementing health and safety regulations.* London, UK: Confederation of British Industry.

Conger, J. A., & Kanungo, R. N. (1987). Toward a behavioral theory of charismatic leadership in organizational settings. *The Academy of Management Review, 12*(4), 637–647. doi:10.5465/AMR.1987.4306715

Conger, J. A., & Kanungo, R. N. (1988). The empowerment process: Integrating theory and practice. *The Academy of Management Review, 13*(3), 471–482. doi:10.5465/AMR.1988.4306983

Conger, J. J., Gaskill, H. S., Glad, D. D., Hassell, L., Rainey, R. V., & Sawrey, W. L. (1959). Psychological and psychophysiological factors in motor vehicle accidents: Follow-up study. *The Journal of the American Medical Association, 169*(14), 1581–1587. doi:10.1001/jama.1959.03000310033008

Conger, J. J., Gaskill, H. S., Glad, D. D., Rainey, R. V., Sawrey, W. L., & Turrell, E. S. (1957). Personal and interpersonal factors in motor vehicle accidents. *American Journal of Psychiatry, 113*(12), 1069–1074. doi:10.1176/ajp.113.12.1069

Conn, V. S., Hafdahl, A. R., Cooper, P. S., Brown, L. M., & Lusk, S. L. (2009). Meta-analysis of workplace physical activity interventions. *American Journal of Preventive Medicine, 37*(4), 330–339. doi:10.1016/j.amepre.2009.06.008

Connell, L., Cai, Z. G., & Holler, J. (2013). Do you see what I'm singing? Visuospatial movement biases pitch perception. *Brain and Cognition, 81*(1), 124–130. doi:10.1016/j.bandc.2012.09.005

Conrad, P. (1988). Worksite health promotion: The social context. *Social Science Medicine, 26*(5), 485–489. doi:10.1016/0277-9536(88)90381-4

Constantinou, E., Panayiotou, G., Konstantinou, N., Loutsiou-Ladd, A., & Kapardis, A. (2011). Risky and aggressive driving in young adults: Personality matters. *Accident Analysis & Prevention, 43*(4), 1323–1331. doi:10.1016/j.aap.2011.02.002

Cook, M. (2004). *Personnel selection: Adding value through people* (4th ed.). Chichester, UK: Wiley.

Cooney, R. E., Atlas, L. Y., Joormann, J., Eugène, F., & Gotlib, I. H. (2006). Amygdala activation in the processing of neutral faces in social anxiety disorder: Is neutral really neutral? *Psychiatry Research: Neuroimaging, 148*(1), 55–59. doi:10.1016/j.pscychresns.2006.05.003

Cooper, C. L. (1996). *The handbook of stress, medicine and health*. Boca Raton, FL: CRC Press.

Cooper, C. L. (1999). The changing psychological contract at work. *European Business Journal, 11*(3), 115–118.

Cooper, C. L., & Bramwell, R. S. (1992). A comparative analysis of occupational stress in managerial and shopfloor workers in the brewing industry: Mental health, job satisfaction and sickness. *Work & Stress, 6*(2), 127–138. doi:10.1080/02678379208260347

Cooper, C. L., & Cartwright, S. (1994). Healthy mind; healthy organization—A proactive approach to occupational stress. *Human Relations, 47*(4), 455–471. doi:10.1177/001872679404700405

Cooper, C. L., Clarke, S. G., & Rowbottom, A. (1999). Occupational stress, job satisfaction and well-being in anaesthetists. *Stress Medicine, 15*(2), 115–126.

Cooper, C. L., Dewe, P. J., & O'Driscoll, M. (2001). *Organizational stress: A review and critique of theory, research and applications*. Thousand Oaks, CA: Sage.

Cooper, C. L., Liukkonen, P., & Cartwright, S. (1996). *Stress prevention in the workplace: Assessing the costs and benefits to organizations*. Luxembourg: European Foundation for the Improvement of Living and Working Conditions. Office for Official Publications of the European Communities.

Cooper, C. L., Mallinger, M., & Kahn, R. (1978). Identifying sources of occupational stress among dentists. *Journal of Occupational Psychology, 51*(3), 227–234. doi:10.1111/j.2044-8325.1978.tb00419.x

Cooper, C. L., & Payne, R. (1988). *Causes, coping and consequences of stress at work*. New York, NY: Wiley.

Cooper, C. L., Rout, U., & Faragher, E. B. (1989). Mental health, job satisfaction and job stress among general practitioners. *British Medical Journal, 298*(366), 366–370. doi:10.1136/bmj.298.6670.366

Cooper, C. L., & Watson, M. (1991). *Cancer and stress: Psychological, biological and coping studies*. Chichester, UK: Wiley.

Cooper, M. D. (2000). Towards a model of safety culture. *Safety Science, 36*(2), 111–136.

Cooper, M. D., & Phillips R. A. (1994). Validation of a safety climate measure. In *Proceedings of the British Psychological Society: Annual Occupational Psychology Conference*. Birmingham, UK, January.

Cooper, M. D., & Phillips, R. A. (1995). Killing two birds with one stone: Achieving total quality via total safety management. *Leadership and Organization Development Journal*, *16*(8), 3–9. doi:10.1108/01437739510097978

Cooper, M. D., & Phillips, R. A. (2004). Exploratory analysis of the safety climate and safety behaviour relationship. *Journal of Safety Research*, *35*(5), 497–512. doi:10.1016/j.jsr.2004.08.004

Cope, T. E., Sedley, W., & Griffiths, T. D. (2011). Timing and the auditory brain. *Advances in Clinical Neuroscience Rehabilitation*, *10*(6), 10–13.

Corden, D. M., Lippold, O. C. J., Buchanan, K., & Norrington, C. (2000). Long-latency component of the stretch reflex in human muscle is not mediated by intramuscular stretch receptors. *Journal of Neurophysiology*, *84*(1), 184–188.

Costa, P. T., & McCrae, R. R. (1985). *The NEO personality inventory manual*. Odessa, FL: Psychological Assessment Resources.

Costa, P. T., & McCrae, R. R. (1992a). Four ways five factors are basic. *Personality and Individual Differences*, *13*(6), 653–665. doi:10.1016/0191-8869(92)90236-I

Costa, P. T., & McCrae, R. R. (1992b). *Revised NEO personality inventory (NEO PI–R) and NEO five–factor inventory (NEO–FFI) professional manual.* Odessa, FL: Psychological Assessment Resources.

Costa, P. T., McCrae, R. R., & Dye, D. A. (1991). Facet scales for agreeableness and conscientiousness: A revision of the NEO personality inventory. *Personality and Individual Differences*, *12*(9), 887–898. doi:10.1016/0191-8869(91)90177-D

Costigan, R. D., Insinga, R. C., Kranas, G., Kureshov, V. A., & Ilter, S. S. (2004). Predictors of employee trust of their CEO: A three-country study. *Journal of Managerial Issues*, *16*(2), 197–216.

Cotton, M. (2015). Structure, agency and post-Fukushima nuclear policy: An alliance-context-actantiality model of political change. *Journal of Risk Research*, *18*(3), 317–332. doi:10.1080/13669877.2014.919512

Couto, B., Salles, A., Sedeño, L., Peradejordi, M., Barttfeld, P., Canales-Johnson, A., … Ibanez, A. (2013). The man who feels two hearts: The different pathways of interoception. *Social Cognitive and Affective Neuroscience*, *9*(9), 1253–1260. doi:10.1093/scan/nst108

Cox, S. J., & Cheyne, A. J. T. (2000). Assessing safety culture in offshore environments. *Safety Science*, *34*(1–3), 111–129.

Cox, S. J., & Cox, T. (1991). The structure of employee attitudes to safety: A European example. *Work & Stress*, *5*(2), 93–106. doi:10.1080/02678379108257007

Cox, S. J., & Cox, T. (1996). *Safety, systems and people*. Oxford, England: Butterworth–Heinemann.

Cox, S. J., & Flin, R. (1998). Safety culture: Philosopher's stone or man of straw? *Work and Stress*, *12*(3), 189–201. doi:10.1080/02678379808256861

Cox, S. J., Jones, B., & Rycraft, H. (2004). Behavioural approaches to safety management within UK reactor plants. *Safety Science*, *42*(9), 825–839. doi:10.1016/j.ssci.2004.03.002

Cox, T. (1985). Repetitive work: Occupational stress and health. In C. L. Cooper & M. J. Smith (Eds.), *Job stress and blue-collar work* (pp. 85–112). Chichester, UK: Wiley.

Cox, T. (1993). *Stress research and stress management: Putting theory to work* (HSE Contract Report no. 61). Sudbury, UK: HSE Books.

Cox, T., & Cox, S. J. (1993). *Psychosocial and organizational hazards: Monitoring and control* (European Series in Occupational Health No. 5). Copenhagen, Denmark: World Health Organization.

Cox, T., & Griffiths, A. (1996). Assessment of psychosocial hazards at work. In M. J. Schabracq, J. A. M. Winnubst, & C. L. Cooper (Eds.), *Handbook of work and health psychology* (pp. 127–143). New York, NY: Wiley.

Cox, T., Griffiths, A., Barlowe, C., Randall, K., Thomson, L., & Rial-Gonzalez, E. (2000). *Organizational interventions for work stress: A risk management approach*. Sudbury, UK: HSE Books.

Cox, T., Griffiths, A., & Cox, S. J. (1993). Stress explosion. *Health & Safety at Work*, June, 16–18.

Cox, T., Griffiths, A., & Cox, S. J. (1995). *Work-related stress in nursing: Managing the risk*. Geneva, Switzerland: International Labor Organization.

Craig, A., & Cooper, R. E. (1992). Acute and chronic fatigue. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance Vol. 3: State and trait* (pp. 289–333). London, UK: Academic Press.

Craig, A. D. (1996). Pain, temperature, and the sense of the body. In O. Franzén, R. J. Lars, & Y. Terenius (Eds.), *Somesthesis and the neurobiology of the somatosensory cortex* (pp. 27–39). Basle, Switzerland: Birkhäuser.

Craig, A. D. (2009). How do you feel—now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, *10*(1), 59–70.
Craig, A. D. B. (2010). The sentient self. *Brain Structure and Function*, *214*(5), 563–577. doi:10.1007/s00429-010-0248-y
Credo, K. R., Armenakis, A. A., Feild, H. S., & Young, R. L. (2010). Organizational ethics, leader-member exchange, and organizational support: Relationships with workplace safety. *Journal of Leadership & Organizational Studies*, *17*(4), 325–334. doi:10.1177/1548051810366712
Crick, F., & Koch, C. (2003). A framework for consciousness. *Nature Neuroscience*, *6*(2), 119–126.
Critchley, H. D., Corfield, D. R., Chandler, M. P., Mathias, C. J., & Dolan, R. J., (2000). Cerebral correlates of autonomic cardiovascular arousal: A functional neuroimaging investigation in humans. *Journal of Physiology*, *523*(1), 259–270. doi:10.1111/j.1469-7793.2000.t01-1-00259
Crombez, G., Viane, I., Eccleston, C., Devulder, J., & Goubert, L. (2013). Attention to pain and fear of pain in patients with chronic pain. *Journal of Behavioral Medicine*, *36*(4), 371–378. doi:10.1007/s10865-012-9433-1
Crosson, C., Barco, P. P., Velozo, C., Bolesta, M. M., Cooper, P. V., Werts, D., & Brobeck, T. C. (1989). Awareness and compensation in postacute head injury rehabilitation. *Journal of Head Trauma Rehabilitation*, *4*(3), 46–54.
Crouch, D. L., Webb, D. O., Peterson, L. V., Buller, P. F., & Rollins, D. E. (1989). A critical evaluation of the Utah Power and Light Company's substance abuse management program: Absenteeism, accidents and costs. In S. W. Gust & J. M. Walsh (Eds.), *Drugs in the workplace: Research and evaluation data* (Research Monograph 91). Rockville, MD: NIDA.
Crowe, J., Lang, A., & Sharkey, D. (2014). Healthcare technology challenges for tiny users. *The Ergonomist*, *526*, 8–9.
Crump, J. H., Cooper, C. L., & Maxwell, V. B. (1981). Stress among air traffic controllers: Occupational sources of coronary heart disease risk. *Journal of Organizational Behavior*, *2*(4), 293–303. doi:10.1002/job.4030020406
Çukur, T., Nishimoto, S., Huth, A. G., & Gallant, J. L. (2013). Attention during natural vision warps semantic representation across the human brain. *Nature Neuroscience*, *16*(6), 763–770. doi:10.1038/nn.3381
Cullen, J. C., & Hammer, L. B. (2007). Developing and testing a theoretical model linking work–family conflict to employee safety. *Journal of Occupational Health Psychology*, *12*(3), 266–278. doi:10.1037/1076-8998.12.3.266
Cullen, W. D. (1990). *Report of the Official Inquiry into the Piper Alpha Disaster*. London, UK: HMSO.
Cummings, C. L., Berube, D. M., & Lavelle, M. E. (2013). Influences of individual-level characteristics on risk perceptions to various categories of environmental health and safety risks. *Journal of Risk Research*, *16*(10), 1277–1295. doi:10.1080/13669877.2013.788544
Cummings, D. E., & Overduin, J. (2007). Gastrointestinal regulation of food intake. *Journal of Clinical Investigation*, *117*(1), 13–23. doi:10.1172/JCI30227
Cunningham, C. J., & De La Rosa, G. M. (2008). The interactive effects of proactive personality and work-family interference on well-being. *Journal of Occupational Health Psychology*, *13*(3), 271–282. doi:10.1037/1076-8998.13.3.271
Dacy, D. (2004). Origins of perception: Retinal ganglion cell diversity and the creation of parallel visual pathways. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 281–301). Cambridge, MA: MIT Press.
Dadashi, N., Wilson, J. R., Golightly, D., & Sharples, S. (2014). A framework to support human factors of automation in railway intelligent infrastructure. *Ergonomics*, *57*(3), 387–402. doi:10.1080/00140139.2014.893026
Dahl, A., Campos, J. J., Anderson, D. I., Uchiyama, I., Witherington, D. C., Ueno, M., … Barbu-Roth, M. (2013). The epigenesis of wariness of heights. *Psychological Science*, *24*(7), 1361–1367. doi:10.1177/0956797613476047
Dahlen, E. R., Edwards, B. D., Tubré, T., Zyphur, M. J., & Warren, C. R. (2012). Taking a look behind the wheel: An investigation into the personality predictors of aggressive driving. *Accident Analysis & Prevention*, *45*, 1–9. doi:10.1016/j.aap.2011.11.012

Dahlen, E. R., Martin, R. C., Ragan, K., & Kuhlman, M. M. (2005). Driving anger, sensation seeking, impulsiveness, and boredom proneness in the prediction of unsafe driving. *Accident Analysis & Prevention*, *37*(2), 341–348. doi:10.1016/j.aap.2004.10.006

Daley, A. J., & Parfitt, G. (1996). Good health—Is it worth it? Mood states, physical well-being, job satisfaction and absenteeism in members and non-members of British corporate health and fitness club. *Journal of Occupational and Organizational Psychology*, *69*(2), 121–134. doi:10.1111/j.2044-8325.1996.tb00604.x

Damasio, A. R. (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. New York, NY: Harcourt Brace.

Damasio, A. R., Grabowski, T. J., Bechara, A., Damasio, H., Ponto, L. L., Parvizi, J., & Hichwa, R. D. (2000). Subcortical and cortical brain activity during the feeling of self-generated emotions. *Nature Neuroscience*, *3*(10), 1049–1056. doi:10.1038/79871

Dansereau, F., Grean, G., & Haga, W. (1975). A vertical dyad linkage approach to leadership within formal organizations: A longitudinal investigation of the role-making process. *Organizational Behavior and Human Performance*, *13*(1), 46–78. doi:10.1016/0030-5073(75)90005-7

Darzentas, D. (2014). The secret lives of objects: Footprints from the internet of things. *The Ergonomist*, *531*, 12–13.

Davachi, L., Romanski, L. M., Chafee, M. V., & Goldman-Rakic, P. S. (2004). Domain specificity in cognitive systems. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 665–678). Cambridge, MA: MIT Press.

Davids, A., & Mahoney, J. T. (1957). Personality dynamics and accident proneness in an industrial setting. *Journal of Applied Psychology*, *41*(5), 303–306. doi:10.1037/h0047608

Davis, H., & McLeod, S. L. (2003). Why humans value sensational news: An evolutionary perspective. *Evolution and Human Behavior*, *24*(3), 208–216. doi:10.1016/S1090-5138(03)00012-6

Davis, J. H., Schoorman, F. D., Mayer, R. C., & Tan, H. H. (2000). The trusted general manager and business unit performance: Empirical evidence of a competitive advantage. *Strategic Management Journal*, *21*(5), 563–576. doi:10.1002/200005.21.5

Davis, J. P., Jansari, A., & Lander, K. (2013). "I never forget a face!" *The Psychologist*, *26*(10), 726–730.

Davis, M., Gendelman, D. S., Tischler, M. D., & Gendelman, P. M. (1982). A primary acoustic startle circuit: Lesion and stimulation studies. *The Journal of Neuroscience*, *2*(6), 791–805.

Davor, M. (2008). Consciousness and pain. In A. I. Basbaum et al. (Eds.), *The senses: A comprehensive reference* (Vol 5, pp. 961–967). London, UK: Academic Press. doi:10.1016/B978-012370880-9.00207-3

Day, A. J., Brasher, K., & Bridger, R. S. (2012). Accident proneness revisited: The role of psychological stress and cognitive failure. *Accident Analysis & Prevention*, *49*, 532–535. doi:10.1016/j.aap.2012.03.028

Day, A. L., & Jreige, S. (2002). Examining Type A behavior pattern to explain the relationship between job stressors and psychosocial outcomes. *Journal of Occupational Health Psychology*, *7*(2), 109–120. doi:10.1037/1076-8998.7.2.109

Day, D. V., & Silverman, S. B. (1989). Personality and job performance: Evidence of incremental validity. *Personnel Psychology*, *42*(1), 25–36. doi:10.1111/j.1744-6570.1989.tb01549.x

de Araujo, I. E. T., Kringelbach, M. L., Rolls, E. T., & McGlone, F. (2003). Human cortical responses to water in the mouth, and the effects of thirst. *Journal of Neurophysiology*, *90*(3), 1865–1876. doi:10.1152/jn.00297.2003

de Arruda Camargo, G. M. P., de Arruda Camargo, L. A., & Saad, W. A. (2007). Vasopressin and angiotensin receptors of the medial septal area of the brain in the control of thirst and salt appetite induced by vasopressin in water-deprived and sodium-depleted rats. *Pharmacology, Biochemistry and Behavior*, *87*(4), 393–399. doi:10.1016/j.ppbb.2007.05.013

De Brabander, B., Hellemans, J., Boone, C., & Gerits, P. (1996). Locus of control, sensation seeking and stress. *Psychological Reports*, *79*(3f), 1307–1312. doi:10.2466/pr0.1996.79.3f.1307

de Bruin, W. B., Stone, E. R., Gibson, J. M., Fischbeck, P. S., & Shoraka, M. B. (2013). The effect of communication design and recipients' numeracy on responses to UXO risk. *Journal of Risk Research*, *16*(8), 981–1004. doi:10.1080/13669877.2013.788055 de Gelder, B., Vroomen, J., & Portois, G. (2004). Multisensory perception of emotion, its time course, and its neural basis. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 581–596). Cambridge, MA: MIT Press.

De Graaf, P., Verfaille, K., Germeys, F., Gysen, V., & Van Eccelpoel, C. (2001). Trans-saccadic representation makes your Porsche go places. *Behavioral and Brain Sciences*, *24*(5), 981–982. doi:10.1017/S140525X01000115

de Lange, A. H., Taris, T. W., Kompier, M. A., Houtman, I. L., & Bongers, P. M. (2003). "The very best of the millennium": Longitudinal research and the demand-control-(support) model. *Journal of Occupational Health Psychology*, *8*(4), 282–305. doi:10.1037/1076-8998.8.4.282

De Martino, B., Kumaran, D., Seymour, B., & Dolan, R. J. (2006). Frames, biases, and rational decision-making in the human brain. *Science*, *313*(5787), 684–687. doi:10.1126/science.1128356

de Mol, B. A. (2014). Regulation of risk management of medical devices and the role of litigation. *Journal of Risk Research*, *17*(6), 735–748. doi:10.1080/13669877.2014.889201

de Rijk, A. E., Le Blanc, P. M., Schaufeli, W. B., & de Jonge, J. (1998). Active coping and need for control as moderators of the job demand-control model: Effects of burnout. *Journal of Occupational and Organizational Psychology*, *71*(1), 1–18. doi:10.1111/j.2044-8325.1998.tb00658.x

De Vocht, M., Cauberghe, V., Uyttendaele, M., & Sas, B. (2015). Affective and cognitive reactions towards emerging food safety risks in Europe. *Journal of Risk Research*, *18*(1), 21–39. doi:10.1080/13669877.2013.879486

Deal, T. E., & Kennedy, A. A. (1986). *Corporate cultures: Rites and rituals of corporate life*. Reading, MA: Addison–Wesley.

Deary, I. J., & Matthews, G. (1993). Personality traits are alive and well. *The Psychologist*, *6*, 299–301.

Deary, I. J., Simonotto, E., Meyer, M., Marshall, A., Marshall, I., Goddard, N., & Wardlaw, J. M. (2004). The functional anatomy of inspection time: An event-related fMRI study. *Neuroimage*, *22*(4), 1466–1479. doi:10.1016/j.neuroimage.2004.03.047

Dębiec, J., Díaz-Mataix, L., Bush, D. E. A., Doyère, V., & LeDoux, J. E. (2010). The amygdala encodes specific sensory features of an aversive reinforcer. *Nature Neuroscience*, *13*(5), 536–537. doi:10.1038/nn.2520

DeChurch, L. A., & Mesmer-Magnus, J. R. (2010). The cognitive underpinnings of effective teamwork: A meta-analysis. *Journal of Applied Psychology*, *95*(1), 32–53. doi:10.1037/a0017328

Dedobbeleer, N., & Béland, F. (1991). A safety climate measure for construction sites. *Journal of Safety Research*, *22*(2), 97–103.

Deffenbacher, J. L., Oetting, E. R., & Lynch, R. S. (1994). Development of a driving anger scale. *Psychological Reports*, *74*(1), 83–91. doi:10.2466/pr0.1994.74.1.83

Dehaene, S., & Changeux, J-P. (2004). Neural mechanisms for access to consciousness. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1145–1157). Cambridge, MA: MIT Press.

Dehaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science*, *5*(5), 303–305.

DeJoy, D. M. (2005). Behavior change versus culture change: Divergent approaches to managing workplace safety. *Safety Science*, *43*(2), 105–129. doi:10.1016/j.ssci.2005.02.001

Dekker, S. (2011). *Drift into failure: From hunting broken components to understanding complex systems*. Aldershot, UK: Ashgate.

Dekker, S. W. (2013). On the epistemology and ethics of communicating a Cartesian consciousness. *Safety Science*, *56*, 96–99. doi:10.1016/j.ssci.2012.05.028

Dekker, S. W. A. (2015). The danger of losing situation awareness. *Cognition, Technology & Work*. online. doi:10.1007/s10111-015-0320-8

Del Parigi, A., Chen, K.-w., Gautier, J.-F., Salbe, A. D., Pratley, R. E., Ravussin, E., … Tataranni, P. A. (2002). Sex differences in the human brain's response to hunger and satiation. *American Journal of Clinical Nutrition*, *75*(6), 1017–1022.

Delarue, A., Van Hootegem, G., Procter, S., & Burridge, M. (2008). Teamworking and organizational performance: A review of survey-based research. *International Journal of Management Reviews*, *10*(2), 127–148. doi:10.1111/j.1468-2370.2007.00227.x

Dembe, A. E., Erickson, J. B., Delbos, R. G., & Banks, S. M. (2006). Nonstandard shift schedules and the risk of job-related injuries. *Scandinavian Journal of Work, Environment & Health*, *32*(3), 232–240.

Demerouti, E., Bakker, A. B., de Jonge, J., Janssen, P. P. M., & Schaufeli, W. B. (2001). Burnout and engagement at work as a function of demands and control. *Scandinavian Journal of Work, Environment and Health*, *27*(4), 279–286.

Demmer, H. (1995). *Work site health promotion: How to go about it* (European Health Promotion Series no. 4). Copenhagen, Denmark: World Health Organization/Europe.

Den Hartog, D. N., & Belschak, F. D. (2012). When does transformational leadership enhance employee proactive behavior? The role of autonomy and role breadth self-efficacy. *Journal of Applied Psychology*, *97*(1), 194–202. doi:10.1037/a0024903

DePasquale, J. P., & Geller, E. S. (1999). Critical success factors for behavior-based safety: A study of twenty industry-wide applications. *Journal of Safety Research*, *30*(4), 237–249. doi:10.1016/S0022-4375(99)00019-5

Derryberry, D., Reed, M. A., & Pilkenton-Taylor, C. (2003). Temperament and coping: Advantages of an individual differences perspective. *Development and Psychopathology*, *15*(4), 1049–1066. doi:10.1017/S0954579403000439

DeRue, D. S., Nahrgang, J. D., Wellman, N., & Humphrey, S. E. (2011). Trait and behavioral theories of leadership: An integration and meta-analytic test of their relative validity. *Personnel Psychology*, *64*(1), 7–52. doi:10.1111/j.1744-6570.2010.01201.x

Desmond, E. (2015). The legitimation of risk and Bt cotton: A case study of Bantala village in Warangal, Andhra Pradesh, India. *Journal of Risk Research*. doi:10.1080/13669877.2014.961516

Detert, J. R. & Burris, E. R. 2007. Leadership behavior and employee voice: Is the door really open? *Academy of Management Journal*, *50*(4), 869–884. doi:10.5465/AMJ.2007.26279183

Devilee, J., Verhoeven, J., Beekman, M., & Knol, A. B. (2015). Can a pre-assessment help us to properly manage controversial risks of chemicals? A discussion on potential improvement of the REACH restriction process. *Journal of Risk Research*. doi:10.1080/13669877.2014.910695

Dias, B. G., & Ressler, K. J. (2013). Parental olfactory experience influences behavior and neural structure in subsequent generations. *Nature Neuroscience*, *17*(1), 89–96. doi:10.1038/nn.3594

Díaz, R. I., & Cabrera, D. D. (1997). Safety climate and attitude as evaluation measures of organizational safety. *Accident Analysis and Prevention*, *29*(5), 643–650. doi:10.1016/S0001-4575(97)00015-8

Díaz-Mataix, L., Dębiec, J., LeDoux, J. E., & Doyère, V. (2011). Sensory-specific associations stored in the lateral amygdala allow for selective alteration of fear memories. *The Journal of Neuroscience*, *31*(26), 9538–9543. doi:10.1523/JNEUROSCI.5808-10.2011

Dieckmann, N. F., Peters, E., Gregory, R., & Tusler, M. (2012). Making sense of uncertainty: Advantages and disadvantages of providing an evaluative structure. *Journal of Risk Research*, *15*(7), 717–735. doi:10.1080/13669877.2012.666760

D'Innocenzo, L., Mathieu, J. E., & Kukenberger, M. R. (2014). A meta-analysis of different forms of shared leadership–team performance relations. *Journal of Management*, *40*, 1–28. doi:10.1177/0149206314525205

Dionne, S. D., Yammarino, F. J., Atwater, L. E., & James, L. R. (2002). Neutralizing substitutes for leadership theory: Leadership effects and common-source bias. *Journal of Applied Psychology*, *87*(3), 454–464. doi:10.1037/0021-9010.87.3.454

Dirks, K. T., & Ferrin, D. L. (2002). Trust in leadership: Meta-analytic findings and implications for research and practice. *Journal of Applied Psychology*, *87*(4), 611–628. doi:10.1037/0021-9010.87.4.611

Dobson, A., Brown, W., Ball, J., Powers, J., & McFadden, M. (1999). Women drivers' behaviour, socio-demographic characteristics and accidents. *Accident Analysis & Prevention*, *31*(5), 525–535. doi:10.1016/S0001-4575(99)00009-3

Dohle, S., Keller, C., & Siegrist, M. (2012). Fear and anger: Antecedents and consequences of emotional responses to mobile communication. *Journal of Risk Research*, *15*(4), 435–446. doi:10.1080/13669877.2011.636835

Dokmanić, I., Parhizkar, R., Walther, A., Lu, Y. M., & Vetterli, M. (2013). Acoustic echoes reveal room shape. *Proceedings of the National Academy of Science*, *110*(30), 12186–12191. doi:10.1073/pnas.1221464110

Dolan, R. J. (2000). Emotional processing in the human brain revealed through functional neuroimaging In Gazzaniga, M. S. (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1115–1131). Cambridge, MA: MIT Press.

Dollard, M. F. (2012). Psychological safety climate: A lead indicator of work conditions, workplace psychological health and engagement and precursor to intervention success. In C. Biron, M. Karanika-Murray, & C. L. Cooper (Eds.), *Improving organizational interventions for stress and well-being: Addressing process and context* (pp. 77–101). Hove, UK: Routledge.

Dollard, M. F., & Bakker, A. B. (2010). Psychosocial safety climate as a precursor to conducive work environments, psychological health problems, and employee engagement. *Journal of Occupational and Organizational Psychology*, *83*(3), 579–599. doi:10.1348/096317909X470690

Dollard, M. F., & Karasek, R. (2010). Building psychosocial safety climate: Evaluation of a socially coordinated PAR risk management stress prevention study. In J. Houdmont & S. Leka (Eds.), *Contemporary occupational health psychology: Global perspectives on research and practice* (pp. 208–234). Chichester, UK: Wiley-Blackwell.

Domenighetti, G., D'Avanzo, B., & Bisig, B. (2000). Health effects of job insecurity among employees in the Swiss general population. *International Journal of Health Services*, *30*(3), 477–490. doi:10.2190/B1KM-VGN7-50GF-8XJ4

Domnisoru, C., Kinkhabwala, A. A., & Tank, D. W. (2013). Membrane potential dynamics of grid cells. *Nature*, *495*(7440), 199–204. doi:10.1038/nature11973

Donnelly, R., Clement, J., Le Heron, R., & St George, J. (2012). Redesigning risk frameworks and registers to support the assessment and communication of risk in the corporate context: Lessons from a corporate risk manager in action. *Risk Management: A Journal of Risk, Crisis and Disaster*, *14*(3), 222–247. doi:10.1057/rm.2012.3

Dorcus, R. M., & Jones, M. H. (1950). *Handbook of employee selection.* New York, NY: McGraw-Hill.

Doty, R. L. (1991a). Psychophysical measurement of odor perception in humans. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 95–134). Berlin, Germany: Springer.

Doty, R. L. (1991b). Influences of aging on human olfactory function. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 181–195). Berlin, Germany: Springer.

Doty, R. L., & Kamath, V. (2014). The influences of age on olfaction: A review. *Frontiers in Psychology*, *6*, 20. doi:10.3389/fpsyg.2014.00020

Drago, R., Wooden, M., & Black, D. (2009). Long work hours: Volunteers and conscripts. *British Journal of Industrial Relations*, *47*(3), 571–600. doi:10.1111/j.1467-8543.2009.00717.x

Dreier, P. (2013). Massacres and movements: Challenging the gun industrial complex. *New Labor Forum*, *22*(2), 92–95. doi:10.1177/1095796013482456

Drichoutis, A. C., & Nayga Jr, R. M. (2013). Eliciting risk and time preferences under induced mood states. *The Journal of Socio-Economics*, *45*, 18–27. doi:10.1016/j.socec.2013.04.008

Driedger, S. M., Mazur, C., & Mistry, B. (2014). The evolution of blame and trust: An examination of a Canadian drinking water contamination event. *Journal of Risk Research*, *17*(7), 837–854. doi:10.1080/13669877.2013.816335

Droit-Volet, S., Ramos, D., Bueno, J. L. O., & Bigand, E. (2013). Music, emotion, and time perception: The influence of subjective emotional valence and arousal? *Frontiers in Psychology*, *4*, 417. doi:10.3389/fpsyg.2013.00417

Drott, L., Jochum, L., Lange, F., Skierka, I., Vach, J., & van Asselt, M. B. A. (2013). Accountability and risk governance: A scenario-informed reflection on European regulation of GMOs. *Journal of Risk Research*, *16*(9), 1123–1140. doi:10.1080/13669877.2012.743161

Duchaine, B. C., & Nakayama, K. (2006). Developmental prosopagnosia: A window to content-specific face processing. *Current Opinion in Neurobiology*, *16*(2), 166–173. doi:10.1016/j.conb.2006.03.003

Duchon, D., Green, S. G., & Taber, T. D. (1986). Vertical dyad linkage: A longitudinal assessment of antecedents, measures, and consequences. *Journal of Applied Psychology*, *71*(1), 56–60. doi:10.1037/0021-9010.71.1.56

Duddington, L., & Seager, L. (2013). How people really use health and wellbeing apps. *The Ergonomist*, *521*, 4–5.

Dudley, S. E. (2014). Comment on Löfstedt's 'The substitution principle in chemical regulation: A constructive critique'. *Journal of Risk Research*, *17*(5), 587–591. doi:10.1080/13669877.2013.873478

Duffy, C. A., & McGoldrick, A. (1990). Stress and the bus driver in the UK transport industry. *Work & Stress*, *4*(1), 17–27. doi:10.1080/02678379008256961

Dugdill, L., & Springett, J. (1994). Evaluation of workplace health promotion: A review. *Health Education Journal*, *53*(3), 337–347. doi:10.1177/001789699405300311

Dulebohn, J. H., Bommer, W. H., Liden, R. C., Brouer, R. L., & Ferris, G. R. (2012). A meta-analysis of antecedents and consequences of leader-member exchange: Integrating the past with an eye toward the future. *Journal of Management*, *38*(6), 1715–1759. doi:10.1177/0149206311415280

Dunbar, R. L. M. (1975). Manager's influence on subordinates' thinking about safety. *The Academy of Management Journal*, *18*(2), 364–369. doi:10.2307/255538

Dunning, D. (2006). Strangers to ourselves. *The Psychologist*, *19*(10), 600–603.

Dunstan D. W., Howard, B., Healy G. N., & Owen, N. (2012). Too much sitting—A health hazard. *Diabetes Research and Clinical Practice*, *97*(3), 368–376. doi:10.1016/j.diabres.2012.05.020

Dunstan, D. W., Kingwell, B. A., Larsen, R., Healy, G. N., Cerin, E., Hamilton, M., … Owen, N. (2012). Breaking up prolonged sitting reduces postprandial glucose and insulin responses. *Diabetes Care*, *35*(5), 976–983. doi:10.2337/dc11-1931

Durodié, B. (2012). The changing nature of riots in the contemporary metropolis from ideology to identity: Lessons from the recent UK riots. *Journal of Risk Research*, *15*(4), 347–354. doi:10.1080/13669877.2011.643479

Durso, F. T., & Dattel, A. R. (2004). SPAM: The real-time assessment of SA. In S. Banbury & S. Tremblay (Eds.), *A cognitive approach to situation awareness: Theory and application* (pp. 137–154). Aldershot, UK: Ashgate.

Durso, F. T., Truitt, T. R., Hackworth, C. A., Crutchfield, J. M., Nikolic, D., Moerti, P. M., … Manning, C. A. (1995). Expertise and chess: Comparing situation awareness methodologies. In D. G. Garland & M. R. Endsley (Eds.), *Proceedings of the International Conference on Experimental Analysis and Measurement of Situation Awareness* (pp. 295–303). Daytona Beach, FL: Embry-Riddle Aeronautical Press.

Dvir, T., Eden, D., Avolio, B. J., & Shamir, B. (2002). Impact of transformational leadership on follower development and performance: A field experiment. *The Academy of Management Journal*, *45*(4), 735–744. doi:10.2307/3069307

Eckert, M. A., Menon, V., Walczak, A., Ahlstrom, J., Denslow, S., Horwitz, A., & Dubno, J. R. (2009). At the heart of the ventral attention system: The right anterior insula. *Human Brain Mapping*, *30*(8), 2530–2541. doi:10.1002/hbm.20688

Eden, D. (1990). Pygmalion without interpersonal contrast effects: Whole groups gain from raising manager expectations. *Journal of Applied Psychology*, *75*(4), 394–398. doi:10.1037/0021-9010.75.4.394

Edkins, G., & Pollock, C. (1997). The influence of sustained attention on railway accidents. *Accident Analysis and Prevention*, *29*(4), 533–539. doi:10.1016/S0001-4575(97)00033-X

Edmondson, A. C. (1996). Learning from mistakes is easier said than done: Group and organizational influences on the detection and correction of human error. *Journal of Applied Behavioral Science*, *32*(1), 5–28. doi:10.1177/0021886396321001

Edmondson, A. C. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly*, *44*(2), 350–383. doi:10.2307/2666999

Edmondson, A. C. (2003). Speaking up in operating room: How team leaders promote learn interdisciplinary action teams. *Journal of Management Studies*, *40*(6), 1419–1452. doi:10.1111/1467-6486.00386

Edwards, J., Baglioni, A., & Cooper, C. L. (1990). Stress, Type-A, coping and psychological and physical symptoms: A multi-sample test of alternative models. *Human Relations*, *43*(10), 919–956. doi:10.1177/001872679004301001

Eichele, T., Debener, S., Calhoun, V. D., Specht, K., Engel, A. K., Hugdahl, K., … Ullsperger, M. (2008). Prediction of human errors by maladaptive changes in event-related brain networks. *Proceedings of the National Academy of Sciences*, *105*(16), 6173–6178. doi:10.1073/pnas.0708965105

Eichenbaum, H. (2004). An information processing framework for memory representation by the hippocampus. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 679–690). Cambridge, MA: MIT Press.

Eid, J., Mearns, K., Larsson, G., Laberg, J. C., & Johnsen, B. H. (2012). Leadership, psychological capital and safety research: Conceptual issues and future research questions. *Safety Science*, *50*(1), 55–61. doi:10.1016/j.ssci.2011.07.001

Eilam, D. (2005). Die hard: A blend of freezing and fleeing as a dynamic defense—implications for the control of defensive behavior. *Neuroscience & Biobehavioral Reviews*, *29*(8), 1181–1191. doi:10.1016/j.neubiorev.2005.03.027

Eimer, M. (2004). Electrophysiological studie of multisensory attention. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 549–562). Cambridge, MA: MIT Press.

Eisler, A. D. (2003). The human sense of time: Biological, cognitive and cultural considerations. In R. Buccheri, M. Sangia, & W. M. Stukey (Eds.), *The nature of time: Geometry, physics and perception* (pp. 5–18). Dordrecht, the Netherlands: Springer.

Elander, J., West, R., & French, D. (1993). Behavioral correlates of individual differences in road-traffic crash risk: An examination of methods and findings. *Psychological Bulletin*, *113*(2), 279–294. doi:10.1037/0033-2909.113.2.279

Elfering, A., Grebner, S., & Ebener, C. (2015). Workflow interruptions, cognitive failure and near-accidents. *Psychology, Health & Medicine*, *20*(2), 139–147. doi:10.1080/13548506.2014.913796

Elfering, A., Semmer, N. K., & Grebner, S. (2006). Work stress and patient safety: Observer-rated work stressors as predictors of characteristics of safety-related events reported by young nurses. *Ergonomics*, *49*(5–6), 457–469. doi:10.1080/00140130600568451

Elko, G. W., & Harney, K. P. (2009). A history of consumer microphones: The electret condenser microphone meets micro-electro-mechanical-systems. *Acoustics Today*, *5*(2), 4–13.

Elliott, M. A., Armitage, C. J. & Baughan, C. J. (2003). Drivers' compliance with speed limits: An application of the theory of planned behavior. *Journal of Applied Psychology*, *88*(5), 964–972. doi:1037/0021-9010.88.5.964

Elliott, T. R., & Maples, S. (1991). Stress management training for employees experiencing corporate acquisition. *Journal of Employment Counselling*, *28*(3), 107–114. doi:10.1002/j.2161-1920.1991.tb00399.x

Elo, A. L., Leppanen, A., & Sillanpaa, P. (1998). Applicability of survey feedback for an occupational health method in stress management. *Occupational Medicine*, *48*(3), 181–188. doi:10.1093/occmed/48.3.181

Emberland, J. S., & Rundmo, T. (2010). Implications of job insecurity perceptions and job insecurity responses for psychological well-being, turnover intentions and reported risk behavior. *Safety Science*, *48*(4), 452–459. doi:10.1016/j.ssci.2009.12.002

Endsley, M. R. (1995a). Towards a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32–64. doi:10.1518/001872095779049543

Endsley, M. R. (1995b). Measurement of situation awareness in dynamic systems. *Human Factors*, *37*(1), 65–84. doi:10.1518/001872095779049499

Epel, E. S., Blackburn, E. H., Li, J., Dhabhar, F. S., Adler, N. E., Morrow, J. D., & Cawthon, R. M. (2004). Accelerated telomere shortening in response to life stress. *Proceedings of the National Academy of Sciences*, *101*(49), 17312–17315. doi:10.1073/pnas.0407162101

Erera-Weatherley, P. L. (1996). Coping with stress: Public welfare supervisors doing their best. *Human Relations*, *49*(2), 157–170. doi:10.1177/001872679604900202

Eriksson, I., Moser, V., Unden, A., & Orth-Gomer, K. (1992). Using knowledge and discussion to decrease stress in Swedish public administration officials. *Conditions of Work Digest*, *11*, 214–219. Geneva, Switzerland: International Labor Office.

Ermer, E., Cosmides, L., & Tooby, J. (2008). Relative status regulates risky decision making about resources in men: Evidence for the co-evolution of motivation and cognition. *Evolution and Human Behavior*, *29*(2), 106–118. doi:10.1016/j.evolhumbehav.2007.11.002

Ernst, M. O. (2008). Multisensory integration: A late bloomer. *Current Biology*, *18*(12), R519–R521. doi:10.1016/j.cub.2008.05.002

Eskritt, M., Doucette, J., & Robitaille, L. (2014). Does future-oriented thinking predict adolescent decision making? *The Journal of Genetic Psychology*, *175*(2), 163–179. doi:10.1080/00221325.2013.875886

European Framework Directive on Health and Safety at Work. (1989). *Council Directive 89/391/EEC of 12 June 1989 on the Introduction of Measures to Encourage Improvements In The Safety and Health of Workers at Work* (Official Journal No. L183, pp. 1–8). Luxembourg.

Evans, G. W., Johansson, G., & Rydstedt, L. (1999). Hassles on the job: A study of a job intervention with urban bus drivers. *Journal of Organizational Behavior, 20*(2), 199–208. doi:10.1002/1099-1379(199903)20.2.199

Evans, G. W., Palsane, M. N., & Carrere, S. (1987). Type A behavior and occupational stress: A cross-cultural study of blue-collar workers. *Journal of Personality and Social Psychology, 52*(5), 1002–1007. doi:10.1037/0022-3514.52.5.1002

Evans, K. C., Wright, C. I., Wedig, M. M., Gold, A. L., Pollack, M. H., & Rauch, S. L. (2008). A functional MRI study of amygdala responses to angry schematic faces in social anxiety disorder. *Depression and Anxiety, 25*(6), 496–505. doi:10.1002/da.20347

Evans, M. G. (1996). R. J. House's "A path-goal theory of leadership effectiveness". *The Leadership Quarterly, 7*(3), 305–309. doi:10.1016/S1048-9843(96)90021-1

Evensen, D. T., Decker, D. J., & Stedman, R. C. (2013). Shifting reactions to risks: A case study. *Journal of Risk Research, 16*(1), 81–96. doi:10.1080/13669877.2012.726238

Eyles, J., & Fried, J. (2012). 'Technical breaches' and 'eroding margins of safety'—Rhetoric and reality of the nuclear industry in Canada. *Risk Management: A Journal of Risk, Crisis and Disaster, 14*(2), 126–151. doi:10.1057/rm.2012.1

Eysenck, H. J. (1970). *The structure of human personality* (3rd ed.). London, UK: Methuen.

Fahlquist, J. N., & Roeser, S. (2015). Nuclear energy, responsible risk communication and moral emotions: A three level framework. *Journal of Risk Research, 18*(3), 333–346. doi:10.1080/13669877.2014.940594

Falcone, B., Coffman, B. A., Clark, V. P., & Parasuraman, R. (2012). Transcranial direct current stimulation augments perceptual sensitivity and 24-hour retention in a complex threat detection task. *PloS One, 7*(4), e34993. doi:10.1371/journal.pone.0034993

Fan, J. X., Brown, B. B., Hanson, H., Kowaleski-Jones, L., Smith, K. R., & Zick, C. D. (2013). Moderate to vigorous physical activity and weight outcomes: Does every minute count? *American Journal of Health Promotion, 28*(1), 41–49. doi:10.4278/ajhp.120606-QUAL-286

Farajnia, S., Deboer, T., Rohling, J. H. T., Meijer, J. H., & Michel, S. (2014). Aging of the suprachiasmatic clock. *The Neuroscientist, 20*(1), 44–55. doi:10.1177/1073858413498936

Farmer, E. (1984). Personality factors in aviation. *International Journal of Aviation Safety, 2*, 175–179.

Farmer, E., & Chambers, E. G. (1926). *A psychological study of individual differences in accident liability* (Industrial Fatigue Research Board Report No. 38). London, UK: HMSO.

Farrell, M. J., Bowala, T. K., Gavrilescu, M., Phillips, P. A., McKinley, M. J., McAllen, R. M., … Egan, G. F. (2011). Cortical activation and lamina terminalis functional connectivity during thirst and drinking in humans. *American Journal of Physiological Regulation and Integrative Comparative Physiology, 301*(3), R623–R631. doi:10.1152/ajpregu.00817.2010

Farrington–Darby, T., Pickup, L., & Wilson, J. R. (2005). Safety culture in railway maintenance. *Safety Science, 43*(1), 39–60. doi:10.1016/j.ssci.2004.09.003

Faure, M. G. (2014). The complementary roles of liability, regulation and insurance in safety management: Theory and practice. *Journal of Risk Research, 17*(6), 689–707. doi:10.1080/13669877.2014.889199

Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P., & Pascual-Leone, A. (2007). Diminishing risk-taking behavior by modulating activity in the prefrontal cortex: A direct current stimulation study. *The Journal of Neuroscience, 27*(46), 12500–12505. doi:10.1523/JNEUROSCI.3283-07.2007

Fecteau, S., Pascual-Leone, A., Zald, D. H., Liguori, P., Théoret, H., Boggio, P. S., & Fregni, F. (2007). Activation of prefrontal cortex by transcranial direct current stimulation reduces appetite for risk during ambiguous decision making. *The Journal of Neuroscience, 27*(23), 6212–6218. doi:10.1523/JNEUROSCI.0314-07.2007

Federal Aviation Administration. (2013). *Operational use of flight path management systems*. Final Report of the Performance-based operations Aviation Rulemaking/Commercial Aviation Safety Team Flight Deck Automation Working Group. Washington, DC: FAA.

Feinberg, T. E. (2013). Neuropathologies of the self and the right hemisphere: A window into productive personal pathologies. *Frontiers in Human Neuroscience*, *7*, 472. doi:10.3389/fnhum.2013.00472

Feinberg, T. E. (2014). The neuropathologies of the self. In A. Chatterjee & H. B. Coslett (Eds.), *The roots of cognitive neuroscience: Behavioral neurology and neuropsychology* (pp. 237–251). Oxford, UK: Oxford University Press.

Feinstein, J. S., Buzza, C., Hurlemann, R., Follmer, R. L., Dahdaleh, N. S., Coryell, W. H., … Wemmie, J. A. (2013). Fear and panic in humans with bilateral amygdala damage. *Nature Neuroscience*, *16*(3), 270–272. doi:10.1038/nn.3323

Feldman, P. J., Cohen, S., Doyle, W. J., Skoner, D. P., & Gwaltney, J. M. (1999). The impact of personality on the reporting of unfounded symptom and illness. *Journal of Personality and Social Psychology*, *77*(2), 370–378. doi:10.1037/0022-3514.77.2.370

Fennell, D. (1988). *Report of the official inquiry into the Kings Cross fire*. London, UK: HMSO.

Ferguson, E., & Cox, T. (1997). The functional dimensions of coping scale: Theory reliability and validity. *British Journal of Health Psychology*, *2*(2), 109–129. doi:10.1111/j.2044-8287.1997.tb00528.x

Festinger, L. (1954). A theory of social comparison processes. *Human Relations*, *7*(2), 117–142. doi:10.1177/001872675400700202

Festinger, L., Riecken, H. W., & Schachter, S. (1956). *When prophecy fails: A social and psychological study of a modern group that predicted the destruction of the world*. Minneapolis, Minnesota: University of Minnesota Press.

Field, R. H. G., & House, R. J. (1990). A test of the Vroom-Yetton model using manager and subordinate reports. *Journal of Applied Psychology*, *75*(3), 362–366. doi:10.1037/0021-9010.75.3.362

Fiedler, F. E. (1967). *Theory of leadership effectiveness*. New York, NY: McGraw-Hill.

Figuié, M. (2014). Towards a global governance of risks: International health organisations and the surveillance of emerging infectious diseases. *Journal of Risk Research*, *17*(4), 469–483. doi:10.1080/13669877.2012.761277

Filion, D. L., Dawson, M. E., & Schell, A. M. (1998). The psychological significance of human startle eyeblink modification: A review. *Biological Psychology*, *47*(1), 1–43. doi:10.1016/S0301-0511(97)00020-3

Filipsson, M., Ljunggren, L., & Öberg, T. (2014). Gender differences in risk management of contaminated land at a Swedish authority. *Journal of Risk Research*, *17*(3), 353–365. doi:10.1080/13669877.2013.808690

Findlay, J. M., & Gilchrist, I. D. (2012). Visual attention—A fresh look. *The Psychologist*, *25*(12), 900–902.

Fine, B. J. (1963). Introversion, extraversion and motor vehicle driver behavior. *Perceptual and Motor Skills*, *16*(1), 95–100. doi:10.2466/pms.1963.16.1.95

Finuncane, M. L., Peters, E., & Slovic, P. (2003). Judgment and decision making: The dance of affect and reason. In S. L. Schneider & J. Shanteau (Eds.), *Emerging perspectives on judgment and decision research* (pp. 327–364). Cambridge, UK: Cambridge University Press.

Fischer, P., Greitemeyer, T., Kastenmüller, A., Vogrincic, C., & Sauer, A. (2011). The effects of risk-glorifying media exposure on risk-positive cognitions, emotions, and behaviors: A meta-analytic review. *Psychological Bulletin*, *137*(3), 367–390. doi:10.1037/a0022267

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behavior: An introduction to theory and research*. Reading, MA: Addison–Wesley.

Fisher, K. (2000). *Leading self–managed work teams*. Toronto, Ontario, Canada: McGraw-Hill.

Fiske, D. W. (1949). Consistency of the factorial structures of personality ratings from different sources. *The Journal of Abnormal and Social Psychology*, *44*(3), 329–344. doi:10.1037/h0057198

Fleishman, E. A., & Harris, E. F. (1962). Patterns of leadership behavior related to employee grievances and turnover. *Personnel Psychology*, *15*(1), 43–56. doi:10.1111/j.1744-6570.1962.tb01845.x

Fleishman, E. A., Harris, E. F., & Burtt, H. E. (1955). *Leadership and supervision in industry: An evaluation of a supervisory training program*. Columbus, OH: Ohio State University. Bureau of Educational Research Monograph (Vol. 33, xiii, 110).

Fleming, M., Flin, R., Mearns, K., & Gordon, R. (1998). Risk perceptions of offshore workers on UK oil and gas platforms. *Risk Analysis*, *18*(1), 103–110. doi:10.1111/j.1539-6924.1998.tb00920.x

Fleming, P., Townsend, E., van Hilten, J. A., Spence, A., & Ferguson, E. (2012). Expert relevance and the use of context-driven heuristic processes in risk perception. *Journal of Risk Research*, *15*(7), 857–873. doi:10.1080/13669877.2012.666759

Fleury-Bahi, G., Préau, M., Annabi-Attia, T., Marcouyeux, A., & Wittenberg, I. (2015). Perceived health and quality of life: The effect of exposure to atmospheric pollution. *Journal of Risk Research*, *18*(2), 127–138. doi:10.1080/13669877.2013.841728

Flin, R. (2001). Selecting the right stuff: Personality and high–reliability occupations. In B. W Roberts & R. Hogan (Eds.), *Personality psychology in the workplace: Decade of behavior* (pp. 253–275). Washington, DC: American Psychological Association.

Flin, R. (2003). 'Danger—men at work': Management influence on safety. *Human Factors and Ergonomics in Manufacturing*, *13*(4), 261–268. doi:10.1002/hfm.10042

Flin, R., Mearns, K., O'Connor, P., & Bryden, R. (2000). Measuring safety climate: Identifying the common features. *Safety Science*, *34*(1–3), 177–192.

Flood, P. C., Hannan, E., Smith, K. G., Turner, T., West, M. A., & Dawson, J. (2000). Chief executive leadership style, consensus decision making, and top management team effectiveness. *European Journal of Work and Organizational Psychology*, *9*(3), 401–420. doi:10.1080/135943200417984

Florin, M-V. (2013). IRGC's approach to emerging risks. *Journal of Risk Research*, *16*(3–4), 315–322. doi:10.1080/13669877.2012.729517

Flynn, R., Ricci, M., & Bellaby, P. (2012). Ambiguity, complexity and uncertainty surrounding the hazards of hydrogen and public views of emergent risks. *Journal of Risk Research*, *15*(4), 373–387. doi:10.1080/13669877.2012.634517

Flynn, R., Ricci, M., & Bellaby, P. (2013). Deliberation over new hydrogen energy technologies: Evidence from two Citizens' Panels in the UK. *Journal of Risk Research*, *16*(3–4), 379–391. doi:10.1080/13669877.2012.743160

Fogarty, G. J., & McKeon, C. M. (2006). Patient safety during medication administration: the influence of organizational and individual variables on unsafe work practices and medication errors. *Ergonomics*, *49*(5–6), 444–456. doi:10.1080/00140130600568410

Fogarty, G. J., & Shaw, A. (2010). Safety climate and the Theory of Planned Behavior: Towards the prediction of unsafe behavior. *Accident Analysis and Prevention*, *42*(5), 1455–1459. doi:10.1016/j.aap.2009.08.008

Folkman, S., & Lazarus, R. S. (1988). Coping as a mediator of emotion. *Journal of Personality and Social Psychology*, *54*(3), 466–475. doi:10.1037/0022-3514.54.3.466

Folkman, S., Lazarus, R. S., Dunkel-Scheffer, C., De Longis, A., & Gruen, R. (1986). Dynamics of a stressful encounter: Cognitive appraisal, coping and encounter outcomes. *Journal of Personality and Social Psychology*, *50*(5), 992–1003. doi:10.1037/0022-3514.50.5.992

Ford, E. S., Li, C-y., Zhao, G-x, Pearson, W. S., Tsai, J., & Churilla, J. R. (2010). Sedentary behavior, physical activity, and concentrations of insulin among US adults. *Metabolism, Clinical and Experimental*, *59*(9), 1268–1275. doi:10.1016/j.metabol.2009.11.020

Ford, M. T., & Tetrick, L. E. (2011). Relations among occupational hazards, attitudes, and safety performance. *Journal of Occupational Health Psychology*, *16*(1), 48–66. doi:10.1037/a0021296

Förster, J., & Denzler, M. (2012). Sense creative! The impact of global and local vision, hearing, touching, tasting and smelling on creative and analytic thought. *Social Psychological and Personality Science*, *3*(1), 108–117. doi:10.1177/1948550611410890

Forster, S., & Lavie, N. (2008). Failures to ignore entirely irrelevant distractors: The role of load. *Journal of Experimental Psychology: Applied*, *14*(1), 73–83. doi:10.1037/1076-898X.14.1.73

Foushee, H. C., Lauber, J. K., Baetge, M. M., & Acomb, D. B. (1986). *New factors in flight operations III: The operational significance of exposure to short–haul air transport operations*. (Technical Memorandum #88342). Moffett Field, CA: NASA–Ames Research Center.

Francis, R. (2013). *Report of the Mid Staffordshire NHS Foundation Trust: Public Inquiry*. London, UK: The Stationery Office.

Franke, R. H., & Kaul, J. D. (1978). The Hawthorne experiments: First statistical interpretation. *American Sociological Review*, *43*(5), 623–643.

Frasnelli, J., Collignon, O., Voss, P., & Lepore, F. (2011). Crossmodal plasticity in sensory loss. In A. M. Green, C. E. Chapman, J. F. Kalaska, & F. Lepore (Eds.), *Progress in brain research, 191* (pp. 233–249). the Netherlands: Elsevier. doi:10.1016/B978-0-444-53752-2.00002-3

Frasnelli, J., Hummel, T., Berg, J., Huang, G., & Doty, R. L. (2011). Intranasal localizability of odorants: Influence of stimulus volume. *Chemical Senses*, *36*(4), 405–410. doi:10.1093/chemse/bjr001

Freeman, J. B., Stolier, R. M., Ingbretsen, Z. A., & Hehman, E. A. (2014). Amygdala responsivity to high-level social information from unseen faces. *The Journal of Neuroscience*, *34*(32), 10573–10581. doi:10.1523/JNEUROSCI.5063-13.2014

Frei, R. L., & McDaniel, M. A. (1997). Validity of customer service measures in personnel selection: A review of criterion and construct evidence. *Human Performance*, *11*(1), 1–27. doi:10.1207/s15327043hup1101_1

Freiwald, W. A., & Kanwisher, N. G. (2004). Visual selective attention: Insights from brain imaging and neurophysiology. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 575–588). Cambridge, MA: MIT Press.

French, D. J., West, R. J., Elander, J., & Wilding, J. M. (1993). Decision-making style, driving style, and self-reported involvement in road traffic accidents. *Ergonomics*, *36*(6), 627–644. doi:10.1080/00140139308967925

Frese, M., Garst, H., & Fay, D. (2007). Making things happen: Reciprocal relationships between work characteristics and personal initiative in a four-wave longitudinal structural equation model. *Journal of Applied Psychology*, *92*(4), 1084–1102. doi:10.1037/0021-9010.92.4.1084

Freund, B., Colgrove, L. A., Burke, B. L., & McLeod, R. (2005). Self-rated driving performance among elderly drivers referred for driving evaluation. *Accident Analysis and Prevention*, *37*(4), 613–618. doi:10.1016/j.aap.2005.03.002

Friedman, M., & Rosenman, R. H. (1974). *Type A behavior and your heart*. New York, NY: Fawcett Crest.

Friedman, M. I., Ulrich, P., & Mattes, R. D. (1999). A figurative measure of subjective hunger sensations. *Appetite*, *32*(3), 395–404. doi:10.1006/appe.1999.0230

Fries, W., & Swihart, A. A. (1990). Disturbance of rhythm sense following right hemisphere damage. *Neuropsychologia*, *28*(12), 1317–1323.

Frost, P. J., Moore, L., Louis, M., Lundberg, C., & Martin, J. (Eds.). (1991). *Reframing organizational culture.* Newbury Park, CA: Sage.

Fugas, C. S., Silva, S. A. & Meliá, J. L. (2012). Another look at safety climate and safety behavior: Deepening the cognitive and social mediator mechanisms. *Accident Analysis and Prevention*, *45*, 468–477. doi:10.1016/j.aap.2011.08.013

Fugas, C. S., Silva, S. A., & Meliá, J. L. (2013). Profiling safety behaviors: Exploration of the sociocognitive variables that best discriminate between different behavioral patterns. *Risk Analysis*, *33*(5), 838–850. doi:10.1111/j.1539-6924.2012.01913.x

Furnham, A., & Saipe, J. (1993). Personality correlates of convicted drivers. *Personality and Individual Differences*, *14*(2), 329–336. doi:10.1016/0191-8869(93)90131-L

Furniss, D., Gould, S., & Iacovides, J. (2013). Errordiary: Sharing strategies for dealing with human error. *The Ergonomist*, *520*, 4–5.

Gaba, D. M., Singer, S. J., Sinaiko, A. D., Bowen, J. D., & Ciavarelli, A. P. (2003). Differences in safety climate between hospital personnel and naval aviators. *Human Factors*, *45*(2), 173–185. doi:10.1518/hfes.45.2.175.27238

Gabbert, S., & Benighaus, C. (2012). Qu vadis integrated testing strategies? Experiences and observations from the work floor. *Journal of Risk Research*, *15*(6), 583–599. doi:10.1080/13669877.2011.646291

Gadd, S., & Collins, A. M. (2002). *Safety culture: A review of the literature.* (HSL/2002/25). Sheffield, England: Health and Safety Laboratory.

Galkin, V. E., Orlova, A., & Egelman, E. H. (2012). Actin filaments as tension sensors. *Current Biology*, *22*(3), R96–R101. doi:10.1016/j.cub.2011.12.010

Gallace, A. (2012). Living with touch. *The Psychologist*, *25*(12), 896–899.

Galperin, A., Fessler, D. M., Johnson, K. L., & Haselton, M. G. (2013). Seeing storms behind the clouds: Biases in the attribution of anger. *Evolution and Human Behavior*, *34*(5), 358–365. doi:10.1016/j.evolhumbehav.2013.06.003

Garcia-Esparcia, P., Schlüter, A., Carmona, M., Moreno, J., Ansoleaga, B., Torrejón-Escribano, B., … Ferrer, I. (2013). Functional genomics reveals dysregulation of cortical olfactory receptors in Parkinson Disease: Novel putative chemoreceptors in the human brain. *Journal of Neuropathology and Experimental Neurology*, *72*(6), 524–539. doi:10.1097/NEN.0b013e318294fd76

Gardiner, K. (2005). Noise. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 222–249). Oxford, UK: Blackwell.

Gardner, W. L., Avolio, B. J., Luthans, F., May, D. R., & Walumbwa, F. (2005). "Can you see the real me?" A self-based model of authentic leader and follower development. *The Leadership Quarterly, 16*(3), 343–372. doi:10.1016/j.leaqua.2005.03.003

Garfinkel, S. N., Minati, L., Gray, M. A., Seth, A. K., Dolan, R. J., & Critchley, H. D. (2014). Fear from the heart: Sensitivity to fear stimuli depends on individual heartbeats. *The Journal of Neuroscience, 34*(19), 6573–6582. doi:10.1523/JNEUROSCI.3507-13.2014

Gaspard, J. C. III, Bauer, G. B., Reep, R. L., Dziuk, K., Read, L., & Mann, D. A. (2013). Detection of hydrodynamic stimuli by the Florida manatee (*Trichechus manatus latirostris*). *Journal of Comparative Physiology A, 199*(6), 441–450. doi:10.1007/s00359-013-0822-x

Gavazzi, G., Bisio, A., & Pozzo, T. (2013). Time perception of visual motion is tuned by the motor representation of human actions. *Scientific Reports, 3*(2430), 1168–1175. doi:10.1038/srep01168

Gazzaniga, M. S. (Ed.). (2000). *The new cognitive neurosciences* (2nd ed.). Cambridge, MA: MIT Press.

Gebreegziabher, K., & Tadesse, T. (2014). Risk perception and management in smallholder dairy farming in Tigray, Northern Ethiopia. *Journal of Risk Research, 17*(3), 367–381. doi:10.1080/13669877.2013.815648

Geller, E. S. (1991). *The psychology of safety handbook*. Boca Raton, FL: CRC Press.

Geller, E. S. (1994). Ten principles for achieving a total safety culture. *Professional Safety, 39*, 18–24.

Geller, E. S. (1996). *The psychology of safety: How to improve behaviors and attitudes on the job*. Radnor, PA: Chilton Book.

Geller, E. S. (1998). *Understanding behavior–based safety: Step–by–step methods to improve your workplace* (2nd ed.). Neenah, WI: J. J. Keller & Associates.

Geller, E. S. (2001). *The psychology of safety handbook*. Boca Raton, FL: CRC Press.

Geller, E. S., & Glaser, H. (1996). *Actively caring for safety*. Dallas TX: Wescott Communications.

Geller, E. S., & Williams, J. H. (2001). *Keys to behavior–based safety*. Bethesda, MD: Government Institutes.

Gellatly, I. R., Paunonen, S. V., Meyer, J. P., Jackson, D. N., & Goffin, R. D. (1991). Personality, vocational interest and cognitive predictors of managerial job performance and satisfaction. *Personality and Individual Differences, 12*(3), 221–231. doi:10.1016/0191-8869(91)90108-N

Gemmell, C., & Scott, M. (2011). Risk, sustainability and the environment (Part I): Guest editorial. *Risk Management: An International Journal, 13*(4), 181–183. doi:10.1057/rm.2011.10

Gemmell, C., & Scott, M. (2012). Risk, sustainability and the environment (Part II): Guest editorial. *Risk Management: A Journal of Risk, Crisis and Disaster, 14*(1), 1–2. doi:10.1057/rm.2011.20

Genovese, E., & Green, C. (2015). Assessment of storm surge damage to coastal settlements in Southeast Florida. *Journal of Risk Research, 18*(4), 407–427. doi:10.1080/13669877.2014.896400

Genovese, E., & Przyluski, V. (2013). Storm surge disaster risk management: The Xynthia case study in France. *Journal of Risk Research, 16*(7), 825–841. doi:10.1080/13669877.2012.737826

George, J. M., & Brief, A. P. (1992). Feeling good—Doing good: A conceptual analysis of the mood at work-organizational spontaneity relationship. *Psychological Bulletin, 112*(2), 310–329. doi:10.1037/0033-2909.112.2.310

Gesser-Edelsburg, A., & Zemach, M. (2012). From a fiasco to the Supertanker grand finale: Israeli Prime Minister Netanyahu's crisis communications during the Carmel disaster. *Journal of Risk Research, 15*(8), 967–989. doi:10.1080/13669877.2012.686052

Getchell, T. V., & Getchell, M. L. (1991). Physiology of olfactory reception and transduction: General principles. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 61–78). Berlin, Germany: Springer.

Gheiratmand, M., Meese, T. S., & Mullen, K. T. (2013). Blobs versus bars: Psychophysical evidence supports two types of orientation response in human color vision. *Journal of Vision, 13*(1), 2. doi:10.1167/13.1.2

Gherardi, S., & Nicolini, D. (2000). The organizational learning of safety in communities of practice. *Journal of Management Inquiry, 9*(1), 7–18. doi:10.1177/105649260091002

Gibbs, M. T. (2012). Time to re-think engineering design standards in a changing climate: The role of risk-based approaches. *Journal of Risk Research, 15*(7), 711–716. doi:10.1080/13669877.2012.657220

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston, MA: Houghton Mifflin.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Giga, S., Faragher, B., & Cooper, C. L. (2003). Part 1: Identification of good practice in stress prevention/management. In J. Jordan, E. Gurr, G. Tinline, S. Giga, B. Faragher, & C. L. Cooper (Eds.), *Beacons of excellence in stress prevention* (pp. 1–45) (HSE Research Report No. 133). Sudbury, UK: HSE Books.

Gilbey, A., & Hill, S. (2012). Confirmation bias in general aviation lost procedures. *Applied Cognitive Psychology, 26*, 785–795. doi:10.1002/acp.2860

Gilkey, D. P., Keefe, T. J., Hautaluoma, J. E., Bigelow, P. L., Herron, R. E., & Stanley, S. A. (2003). Management commitment to safety and health in residential construction: HomeSafe spending trends 1991–1999. *Work: Journal of Prevention, Assessment & Rehabilitation, 20*(1), 35–44.

Gill, F. (2005). Ventilation. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 440–459). Oxford, UK: Blackwell.

Gillen, M., Baltz, D., Gassel, M., Kirsch, L., & Vaccaro, D. (2002). Perceived safety climate, job demands, and coworker support among union and non-union injured construction workers. *Journal of Safety Research, 33*(1), 33–51. doi:10.1016/S0022-4375(02)00002-6

Gillen, M., Kools, S., McCall, C., Sum, J., & Moulden, K. (2004). Construction managers' perceptions of construction safety practices in small and large firms: A qualitative investigation. *Work: Journal of Prevention, Assessment & Rehabilitation, 23*(3), 233–243.

Girling, J. (2014). Commentary on the Löfstedt substitution paper. *Journal of Risk Research, 17*(5), 593–595. doi:10.1080/13669877.2013.875937

Glendon, A. I. (1979). Accident prevention and safety: Whose responsibility? *Occupational Health, 31*(1), 31–37.

Glendon, A. I. (1980). Safety: Whose responsibility 2? *Occupational Health, 32*(8), 408–412.

Glendon, A. I. (1981). What does responsibility mean? *Occupational Health, 33*(5), 245–250.

Glendon, A. I. (2005). Young drivers' attitudes towards risks arising from hazardous driving behaviours. In L. Dorn (Ed.), *Driver behaviour and training* (pp. 193–206). Aldershot, England: Ashgate.

Glendon, A. I. (2006). Safety culture. In W. Karwoski (Ed.), *International encyclopedia of ergonomics and human factors* (2nd ed., pp. 2287–2294). London, UK: Taylor & Francis.

Glendon, A. I. (2007). Driving violations observed: An Australian study. *Ergonomics, 50*(8), 1159–1182. doi:10.1080/00140130701318624

Glendon, A. I. (2011a). Neuroscience and young drivers. In B. Porter (Ed.), *Handbook of traffic psychology* (pp. 109–125). Amsterdam, the Netherlands: Elsevier.

Glendon, A. I. (2011b). Safety and risk in transportation. In R. J. Burke, S. G. Clarke, & C. L. Cooper (Eds.), *Occupational health and safety: Psychological and behavioral aspects of risk* (pp. 239–275). Farnham, UK: Gower.

Glendon, A. I. (2014). An approach to novice driver training. *European Review of Applied Psychology, 64*(3), 111–122. doi:10.1016/j.erap.2014.04.003

Glendon, A. I. (2015). Risk management: An international perspective. In S. Clarke, T. Probst, F. Guldenmund, & J. Passmore (Eds.), *The Wiley-Blackwell handbook of the psychology of occupational safety and workplace health*. Chichester, UK: Wiley-Blackwell.

Glendon, A. I., & Coles, F. (2001). Stress in ambulance staff. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload and fatigue: Theory, research and practice* (pp. 167–199). Mahwah, NJ: Erlbaum.

Glendon, A. I., & Litherland, D. K. (2001). Safety climate factors, group differences and safety behavior in road construction. *Safety Science, 39*(3), 157–188.

Glendon, A. I., & Stanton, N. A. (2000). Perspectives on safety culture. *Safety Science, 34*(1–3), 193–213.

Glendon, A. I., & Sutton, D. C. (2005). Observing motorway driving violations. In D. A. Hennessey & D. L. Wiesenthal (Eds.), *Contemporary issues in road user behavior and traffic safety* (pp. 77–97). New York, NY: Nova Science.

Glendon, I. (2008). Safety culture: Snapshot of a developing concept. *Journal of Occupational Health & Safety: Australia and New Zealand, 24*(3), 179–189.

Goldberg, A. I., Dar-El, E. M., & Rubin, A. E. (1991). Threat perception and the readiness to participate in safety programs. *Journal of Organizational Behavior, 12*(2), 109–122. doi:10.1002/job.4030120204

Goldberg, L. R. (1990). An alternative "description of personality": The big-five factor structure. *Journal of Personality and Social Psychology*, *59*(6), 1216–1229. doi:10.1037/0022-3514.59.6.1216
Goldberg, L. R. (1992). The development of markers for the big-five factor structure. *Psychological Assessment*, *4*(1), 26–42. doi:10.1037/1040-3590.4.1.26
Goldberg, L. R. (1993). The structure of phenotypic personality traits. *American Psychologist*, *48*(1), 26–34. doi:10.1037/0003-066X.48.1.26
Goldgruber, J., & Ahrens, D. (2010). Effectiveness of workplace health promotion and primary prevention interventions: A review. *Journal of Public Health*, *18*(1), 75–88. doi:10.1007/s10389-009-0282-5
Golightly, D., Ryan, B., Dadashi, N., Pickup, L., & Wilson, J. R. (2013). Use of scenarios and function analyses to understand the impact of situation awareness on safe and effective work on rail tracks. *Safety Science*, *56*, 52–62. doi:10.1016/j.ssci.2012.08.007
Goodale, N. A. (2004). Perceiving the world and grasping it: Dissociations between conscious and unconscious visual processing. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1159–1172). Cambridge, MA: MIT Press.
Goodman, P. S. (1979). *Assessing organizational change: The Rushton quality of work experiment*. New York, NY: Wiley.
Goodman, P. S., Devadas, R., & Hughson, T. G. (1988). Groups and productivity: Analyzing the effectiveness of self–managing teams. In J. P. Campbell, R. J. Campbell, E. A. Fleishman, I. L. Goldstein, J. R. Hackman, L. W. Porter, & V. H. Vroom (Eds.), *Productivity in organizations* (pp. 295–327). San Francisco, CA: Jossey–Bass.
Gordon, M. S. (2012). Finding the senses. *The Psychologist*, *25*(12), 908–909.
Gori, M., Del Viva, M., Sandini, G., & Burr, D. C. (2008). Young children do not integrate visual and haptic information. *Current Biology*, *18*(9), 694–698. doi:10.1016/j.cub.2008.04.036
Gouldner, A. W. (1955). *Patterns of industrial bureaucracy*. London, UK: Routledge.
Graen, G., Orris, J. B., & Alvares, K. M. (1971). Contingency model of leadership effectiveness: Some experimental results. *Journal of Applied Psychology*, *55*(3), 196–201. doi:10.1037/h0031093
Graen, G., & Uhl-Bien, M. (1995). Relationship based approach to leadership development of leader–member exchange (LMX) theory of leadership over 25 years: Applying a multi-level multi-domain perspective. *The Leadership Quarterly*, *6*(2), 219–247. doi:10.1016/1048-9843(95)90036-5
Granrud, C. E., & Schmechel, T. T. (2006). Development of size constancy in children: A test of the proximal mode sensitivity hypothesis. *Perception & Psychophysics*, *68*(8), 1372–1381. doi:10.3758/BF03193736
Grant, S., & Langan-Fox, J. (2006). Occupational stress, coping and strain: The combined/interactive effect of the Big Five traits. *Personality and Individual Differences*, *41*(4), 719–732. doi:10.1016/j.paid.2006.03.008
Gray, J. A. (1987). Perspectives on anxiety and impulsivity: A commentary. *Journal of Research in Personality*, *21*(4), 493–509. doi:10.1016/0092-6566(87)90036-5
Graziano, M. S. A., Gross, C. G., Taylor, C. S. R., & Moore, T. (2004). Multisensory neurons for the control of defensive movements. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 443–452). Cambridge, MA: MIT Press.
Graziano, M. S. A., & Kastner, S. (2011a). Human consciousness and its relationship to social neuroscience: A novel hypothesis. *Cognitive Neuroscience*, *2*(2), 98–113. doi:10.1080/17588928.2011.565121
Graziano, M. S. A., & Kastner, S. (2011b). Awareness as a perceptual model of attention. *Cognitive Neuroscience*, *2*(2), 125–133. doi:10.1080/17588928.2011.585237
Great Britain: Department of Transport. (1989). *Investigation into the Clapham Junction railway accident*. Anthony Hidden QC (Cmnd. 820). London, UK: HMSO.
Great Britain: Department of Transport, Air Accidents Investigation Branch. (1990). Aircraft Accident Report 4/90: Report on the Accident to Boeing 737–400 G-OBME near Kegworth, Leicestershire on 8 January 1989. London, UK: HMSO.
Great Britain: Ministry of Transport. (1968). *Report of the Public Inquiry into the Accident at Hixon Level Crossing on January 6th 1968*. (Cmnd. 3706). London, UK: HMSO.
Greenwood, M., & Woods, H. M. (1919). A report on the incidence of industrial accidents upon individuals with special reference to multiple accidents. In W. Haddon, E. A. Suchman, & D. Klein (Eds.) (1964), *Accident proneness*. New York, NY: Harper and Row.

Greenwood, M., & Yule, G. U. (1920). An enquiry into the nature of frequency distributions representative of multiple happenings, with particular reference to the occurrence of multiple attacks of disease or of repeated accidents. *Journal of the Royal Statistical Society*, *83*(2), 255–279.

Greiner, B. A., Krause, N., Ragland, D. R., & Fisher, J. M. (1998). Objective stress factors, accidents, and absenteeism in transit operators: A theoretical framework and empirical evidence. *Journal of Occupational Health Psychology*, *3*(2), 130–146. doi:10.1037/1076-8998.3.2.130.

Griffin, M. A., & Clarke, S. (2011). Stress and well-being at work. In S. Zedeck (Ed.), *APA handbook of industrial and organizational psychology, Vol 3: Maintaining, expanding, and contracting the organization* (pp. 359–397). Washington, DC: American Psychological Association. doi:10.1037/12171-010

Griffin, M. A., Hart, P. M., & Wilson-Evered, E. (2000). Using employee opinion surveys to improve organizational health. In L. R. Murphy & C. L. Cooper (Eds.), *Healthy and productive work: An international perspective* (pp. 15–36). London, UK: Taylor & Francis.

Griffin, M. A., & Hu, X. (2013). How leaders differentially motivate safety compliance and safety participation: The role of monitoring, inspiring, and learning. *Safety Science*, *60*, 196–202. doi:10.1016/j.ssci.2013.07.019

Griffin, M. A., & Neal, A. (2000). Perceptions of safety at work: A framework for linking safety climate to safety performance, knowledge, and motivation. *Journal of Occupational Health Psychology*, *5*(3), 347–358. doi:10.1037/1076-8998.5.3.347

Griffin, M., Neal, A., & Rafferty, A. (2002). *The influence of leadership and safety climate on safety behavior*. Paper presented at the Conference of the 25th International Congress of Applied Psychology, Singapore

Griffin, M. J. (2005). Vibration. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 250–267). Oxford, UK: Blackwell.

Griffiths, T. D., Johnsrude, I., Dean, J. L., & Green, G. G. (1999). A common neural substrate for the analysis of pitch and duration pattern in segmented sound? *Neuroreport*, *10*(18), 3825–3830.

Grillon, C., Pellowski, M., Merinkangas, K. R., & Davis, M. (1997). Darkness facilitates acoustic startle reflex in humans. *Biological Psychiatry*, *42*(6), 453–460. doi:10.1016/S0006-3223(96)00466-0

Grinde, B. (2013). The evolutionary rationale for consciousness. *Biological Theory*, *7*(3), 227–236. doi:10.1007/s13752-012-0061-3

Groeger, J., A., & Brown, I. D. (1989). Assessing one's own and others' driving ability: Influence of sex, age, and experience. *Accident Analysis & Prevention*, *21*(2), 155–168. doi:10.1016/0001-4575(89)90083-3

Groeneweg, J. (1992). *Controlling the controllable: The management of safety*. Leiden, the Netherlands: DSWO Press.

Groso, A., Ouedraogo, A., & Mayer, T. (2012). Risk analysis in research environment. *Journal of Risk Research*, *15*(2), 187–208. doi:10.1080/13669877.2011.634513

Gross, C. T., & Canteras, N. S. (2012). The many paths to fear. *Nature Reviews Neuroscience*, *13*(9), 651–658. doi:10.1038/nrn3301

Grossman, A. H., & Silverstein, C. (1993). Facilitating support groups for professionals working with AIDS. *Social Work*, *38*(2), 144–151. doi:10.1093/sw/38.2.144

Grote, G. (2008). Diagnosis of safety culture: A replication and extension towards assessing "safe" organizational change processes. *Safety Science*, *46*, 450–460.doi:10.1016/j.ssci.2007.05.005.

Grote, G. (2009). *Management of uncertainty: Theory and application in the design of systems and organizations*. London, UK: Springer.

Grote, G. (2012). Safety management in different high-risk domains: All the same? *Safety Science*, *50*(10), 1983–1992. doi:10.1016/j.ssci.2011.07.017

Grote, G. (2015). Promoting safety by increasing uncertainty: Implications for risk management. *Safety Science*, *71*(B), 71–79. doi:10.1016/j.ssci.2014.02.010

Grote, G. & Künzler, C. (2000). Diagnosis of safety culture in safety management audits. *Safety Science*, *34*(1–3), 131–150.

Grote, G., Weichbrodt, J. C., Gunter, H., Zala-Mezo, E., & Kunzle, B. (2009). Coordination in high-risk organizations: The need for flexible routines. *Cognition, Technology and Work*, *11*(1), 17–27. doi:10.1007/s10111-008-0119-y

Guest, D. E., Peccei, R., & Thomas, A. (January 1994). *Safety culture and safety performance: British Rail in the aftermath of the Clapham Junction disaster*. Occupational Psychology Conference of the British Psychological Society, Birmingham, UK.

Guilford, J. S. (1973). Prediction of accidents in a standardized home environment. *Journal of Applied Psychology*, *57*(3), 306–313. doi:10.1037/h0034725

Guillard-Gonçalves, C., Cutter, S. L., Emrich, C. T., & Zêzere, J. L. (2015). Application of Social Vulnerability Index (SoVI) and delineation of natural risk zones in Greater Lisbon, Portugal. *Journal of Risk Research*, *18*(5), 651–674. doi:10.1080/13669877.2014.910689

Guldenmund, F. W. (2000). The nature of safety culture: A review of theory and research. *Safety Science*, *34*(1–3), 215–257.

Guldenmund, F. W. (2007). The use of questionnaires in safety culture research: An evaluation. *Safety Science*, *45*(6), 723–743. doi:10.1016/j.ssci.2007.04.006

Guldenmund, F. W. (2010). (Mis)understanding safety culture and its relationship to safety management. *Risk Analysis*, *30*(10), 1466–1480. doi:10.1111/j.1539-6924.2010.01452.x

Gulian, E., Glendon, A. I., Davies, D. R., Matthews, G., & Debney, L. M. (1990). The stress of driving: A diary study. *Work & Stress*, *4*(1), 7–16. doi:10.1080/02678379008256960

Gully, S. M., Devine, D. J., & Whitney, D. J. (1995). A meta–analysis of cohesion and performance: Effects of levels of analysis and task interdependence. *Small Group Research*, *26*(4), 497–520. doi:10.1177/1046496495264003

Guppy, A., & Marsden. J. (1996). Alcohol and drug misuse and the organization. In M. J. Schabracq, J. A. M. Winnubst, & C. L. Cooper (Eds.), *Handbook of work and health psychology* (pp. 231–255). New York, NY: Wiley.

Gupta, V. K., Huang, R., & Niranjan, S. (2010). A longitudinal examination of the relationship between team leadership and performance. *Journal of Leadership & Organizational Studies*, *17*(4), 335–350. doi:10.1177/1548051809359184

Guy, C., & Ffytche, D. (2005). *An introduction to the principles of medical imaging* (Rev. ed.). London, UK: Imperial College Press.

Guzzo, R. A. (1996). Fundamental considerations about work groups. In M. A. West (Ed.), *Handbook of work group psychology* (pp. 3–24). Chichester, England: Wiley.

Haase, L., Cerf-Ducastel, B., & Murphy, C. (2009). Cortical activation in response to pure taste stimuli during the physiological states of hunger and satiety. *NeuroImage*, *44*(3), 1008–1021. doi:10.1016/j.neuroimage.2008.09.044

Hackman, J. R. (1994). Trip wires in designing and leading workgroups. *The Occupational Psychologist*, 23, 3–8.

Hackman, J. R. (1998). Why teams don't work. In R. S. Tindall, J. Edwards, & E. J. Posavac (Eds.), *Theory and research on small groups* (pp. 277–301). New York, NY: Plenum.

Hadjikhani, N., Kveraga, K., Naik, P., & Ahlfors, S. P. (2009). Early (N170) activation of face-specific cortex by face-like objects. *Neuroreport*, *20*(4), 403–407. doi:10.1097/WNR.0b013e328325a8e1

Hagenaars, M. A., Roelofs, K., & Stins, J. F. (2013). Human freezing in response to affective films. *Anxiety, Stress & Coping*, *27*(1), 27–37. doi:10.1080/10615806.2013.809420

Hagenaars, M. A., Stins, J. F., & Roelofs, K. (2012). Aversive life events enhance human freezing responses. *Journal of Experimental Psychology: General*, *141*(1), 98–105. doi:10.1037/a0024211

Hagmann, J. (2012). Fukushima: Probing the analytical and epistemological limits of risk analysis. *Journal of Risk Research*, *15*(7), 801–815. doi:10.1080/13669877.2012.657223

Haigh, A., Brown, D. J., Meijer, P., & Proulx, M. J. (2013). How well do you see what you hear? The acuity of visual-to-auditory sensory substitution. *Frontiers in Psychology*, *4*, 330. doi:10.3389/fpsyg.2013.00330

Hakanen, J. J., Schaufeli, W. B., & Ahola, K. (2008). The job demands-resources model: A three-year cross-lagged study of burnout, depression, commitment, and work engagement. *Work & Stress*, *22*(3), 224–241. doi:10.1080/02678370802379432

Hakkinen, S. (1958). *Traffic accidents and driver characteristics: A statistical and psychological study* (Doctoral dissertation). Helsinki: Finland Institute of Technology.

Halbesleben, J. R. B. (2010). The role of exhaustion and workarounds in predicting occupational injuries: A cross-lagged panel study of health care professionals. *Journal of Occupational Health Psychology*, *15*(1), 1–16. doi:10.1037/a0017634

Halbesleben, J. R. B., Leroy, H., Dierynck, B., Simons, T., Savage, G. T., McCaughey, D., & Leon, M. R. (2013). Living up to safety values in health care: The effect of leader behavioral integrity on occupational safety. *Journal of Occupational Health Psychology*, *18*(4), 395–405. doi:10.1037/a0034086

Halbesleben, J. R. B., Wakefield, D. S., & Wakefield, B. J. (2008). Work-arounds in health care settings: literature review and research agenda. *Health Care Management Review*, *33*(1), 2–12. doi:10.1097/01.HMR.0000304495.95522ca

Hale, A. R., Guldenmund, F. W., van Loenhout, P. L. C. H., & Oh, J. I. H. (2010). Evaluating safety management and culture interventions to improve safety: Effective intervention strategies. *Safety Science*, *48*(8), 1026–1035. doi:10.1016/j.ssci.2009.05.006

Hale, A. R., & Hale, M. (1972). *A review of the industrial accident literature*. London, UK: HMSO.

Hale, A. R., & Hovden, J. (1998). Managing culture: The third age of safety. A review of approaches to organizational aspects of safety health and environment. In A. Williamson & A.-M. Feyer (Eds.), *Occupational injury: Risk, prevention and injury* (pp. 129–166). London, UK: Taylor & Francis.

Halligan, M. H., Zecevic, A., Kothari, A. R., Salmoni, A. W., & Orchard, T. (2014). Understanding safety culture in long-term care: A case study. *Journal of Patient Safety*, *10*(4), 192–201. doi:10.1097/PTS.0b013e31829d4ae7

Hallschmid, M., Mölle, M., Wagner, U., Fehm, H. L., & Born, J. (2001). Drinking related direct current positive potential shift in the human EEG depends on thirst. *Neuroscience Letters*, *311*(3), 173–176. doi:10.1016/S0304-3940(01)02164-4

Hameroff, S., Trakas, M., Duffield, C., Annabi, E., Bagambhrini Gerace, M., Boyle, P., … Badal, J. J. (2013). Transcranial ultrasound (TUS) effects on mental states: A pilot study. *Brain Stimulation*, *6*(3), 409–415. doi:10.1016/j.brs.2012.05.002

Han, C.-R., & Ireland, R. (2014). Performance measurement of the KCS customs selectivity system. *Risk Management: A Journal of Risk, Crisis and Disaster*, *16*(1), 25–43. doi:10.1057/rm.2014.2

Han, S. W., Lee, M. J., & Moon, K. H. (2009). Acceleration thresholds of vertical floor vibrations according to human perception levels in Korea. *Advances in Structural Engineering*, *12*(4), 595–607. doi:10.1260/136943309789508537

Hansen, C. P. (1988). Personality characteristics of the accident involved employee. *Journal of Business and Psychology*, *2*(4), 346–365. doi:10.1007/BF01013766

Hansen, C. P. (1989). A causal model of the relationship among accidents, biodata, personality and cognitive factors. *Journal of Applied Psychology*, *74*(1), 81–90. doi:10.1037/0021-9010.74.1.81

Hansez, I., & Chmiel, N. (2010). Safety behavior: Job demands, job resources, and perceived management commitment to safety. *Journal of Occupational Health Psychology*, *15*(3), 267–278. doi:10.1037/a0019528

Hansson, H., & Lagerkvist, C. J. (2012). Measuring farmers' preferences for risk: A domain-specific risk preference scale. *Journal of Risk Research*, *15*(7), 737–753. doi:10.1080/13669877.2012.657217

Hao, S., Sternini, C., & Raybould, H. E. (2008). Role of CCK_1 and Y_2 receptors in activation of hindbrain neurons induced by intragastric administration of bitter taste receptor ligands. *American Journal of Physiological Regulation and Integrative Comparative Physiology*, *294*(1), R33–R38. doi:10.1152/ajpregu.00675.2007

Harbeck, E. L., & Glendon, A. I. (2013). How reinforcement sensitivity and perceived risk influence young drivers' reported engagement in risky driving behaviors. *Accident Analysis and Prevention*, *54*, 73–80. doi:10.1016/j.aap.2013.02.011

Harber, K. D., Yeung, D., & Iacovelli, A. (2011). Psychosocial resources, threat, and the perception of distance and height: Support for the resources and perception model. *Emotion*, *11*(5), 1080–1090. doi:10.1037/a0023995

Hardy, C., & Leiba-O'Sullivan, S. (1998). The power behind empowerment: Implications for research and practice. *Human Relations*, *51*(4), 451–483. doi:10.1023/A:1016989830806

Hardy, G. E., Shapiro, D. A., & Borrill, C. S. (1997). Fatigue in the workforce of National Health Service trusts: Levels of symptomatology and links with minor psychiatric disorder, demographic, occupational and work role factors. *Journal of Psychosomatic Research*, *43*(1), 83–92. doi:10.1016/S0022-3999(97)00019-6

Harré, N., Brandt, T., & Dawe, M. (2000). The development of risky driving in adolescence. *Journal of Safety Research*, *31*(4), 185–194. doi:10.1016/S0022-4375(00)00035-9

Harrell, W. A. (1990). Perceived risk of occupational injury: Control over pace of work and blue-collar versus white-collar work. *Perceptual and Motor Skills, 70*(3c), 1351–1359. doi:10.2466/pms.1990.70.3c.1351

Harris, D. A. (2010). Picture this: Body-worn video devices (head cams) as tools for ensuring Fourth Amendment compliance by police. *Texas Tech Law Review, 43,* 257–371.

Harris, J. R. (1991). The utility of the transactional approach for occupational stress research. *Journal of Social Behavior and Personality, 6*(7), 21–29.

Harsay, H. A., Spaan, M., Wijnen, J. G., & Ridderinkhof, K. R. (2012). Error awareness and salience processing in the oddball task: Shared neural mechanisms. *Frontiers in Human Neuroscience, 6,* 246. doi:10.3389/fnhum.2012.00246

Hart, P. M. (1994). Teacher quality of work life: Integrating work experiences, psychological distress and morale. *Journal of Occupational and Organizational Psychology, 67*(2), 109–132. doi:10.1111/j.2044-8325.1994.tb00555.x

Hart, P. M., Wearing, A. J., & Headey, B. (1995). Police stress and well-being: Integrating personality, coping and daily work experiences. *Journal of Occupational and Organizational Psychology, 68*(2), 133–156. doi:10.1111/j.2044-8325.1995.tb00578.x

Hart, T., Giovannetti, T., Montgomery, M. W., & Schwartz, M. F. (1998). Awareness of errors in naturalistic action after traumatic brain injury. *The Journal of Head Trauma Rehabilitation, 13*(5), 16–28.

Hartling, L., Newton, A. S., Liang, Y.-y., Jou, H., Hewson, K., Klassen, T. P., & Curtis, S. (2013). Music to reduce pain and distress in the pediatric emergency department. *JAMA Pediatrics, 167*(9), 826–835. doi:10.1001/jamapediatrics.2013.200

Harvey, J., Erdos, G., Bolam, H., Cox, M. A. A., Kennedy, J. N. P., & Gregory, D. T. (2002). An analysis of safety culture attitudes in a highly regulated environment. *Work & Stress, 16*(1), 18–36. doi:10.1080/02678370110113226

Haselton, M. G., Bryant, G. A., Wilke, A., Frederick, D. A., Galperin, A., Frankenhuis, W. E., & Moore, T. (2009). Adaptive rationality: An evolutionary perspective on cognitive bias. *Social Cognition, 27*(5), 733–763. doi:10.1521/soco.2009.27.5.733

Haselton, M. G., & Buss, D. M. (2000). Error management theory: A new perspective on biases in cross-sex mind reading. *Journal of Personality and Social Psychology, 78*(1), 81–91. doi:10.1037110022-3514.78.1.81

Haselton, M. G., & Galperin, A. (2012). Error management and the evolution of cognitive bias. In J. P. Forgas, K. Fiedler, & C. Sedikedes (Eds.), *Social thinking and interpersonal behavior* (pp. 45–64). New York, NY: Psychology Press.

Haselton, M. G., & Nettle, D. (2006). The paranoid optimist: An integrative evolutionary model of cognitive biases. *Personality and Social Psychology Review, 10*(1), 47–66. doi:10.1207/s15327957pspr1001_3

Haselton, M. G., Nettle, D., & Andrews, P. W. (2005). The evolution of cognitive bias. In D. M. Buss (Ed.), *The handbook of evolutionary psychology* (pp. 724–746). Hoboken, NJ: Wiley.

Hatfield, J., Fernandes, R., & Job, S. R. F. (2014). Thrill and adventure seeking as a modifier of the relationship of perceived risk with risky driving among young drivers. *Accident Analysis & Prevention, 62,* 223–229. doi:10.1016/j.aap.2013.09.028

Haque, M. M., & Washington, S. (2013). Effects of mobile phone distraction on drivers' reaction times. *Journal of the Australasian College of Road Safety, 24*(3), 20–29.

Haukelid, K. (2008). Theories of (safety) culture revisited: An anthropological approach. *Safety Science, 46*(3), 413–426. doi:10.1016/j.ssci.2007.05.014

Häusser, J. A., Mojzisch, A., Niesel, M., & Schulz-Hardt, S. (2010). Ten years on: A review of recent research on the job demand-control (-support) model and psychological well-being. *Work & Stress, 24*(1), 1–35. doi:10.1080/02678371003683747

Hayashida, Y., Gonzalez, C., & Kondo, H. (Eds.). (2006). *The arterial chemoreceptors*. New York, NY: Springer.

He, G-z., Mol, A. P. J., Zhang, L., & Lu, Y-l. (2014). Nuclear power in China after Fukushima: Understanding public knowledge, attitudes, and trust. *Journal of Risk Research, 17*(4), 435–451. doi:10.1080/13669877.2012.726251

He, G-z., Zhang, L., Mol, A. P. J., & Lu, Y-l. (2013). Profiling the environmental risk management of Chinese local environmental agencies. *Journal of Risk Research*, *16*(10), 1259–1275. doi:10.1080/13669877.2013.788060

Health and Safety Commission (HSC). (1993). Advisory Committee on the Safety of Nuclear Installations, ACSNI Study Group on Human Factors (1993). *Third report: Organising for safety.* London, UK: HMSO.

Hechanova-Alampay, R. H., & Beehr, T. A. (2002). Empowerment, span of control and safety performance in work teams after workforce reduction. *Journal of Occupational Health Psychology*, *6*(4), 275–282. doi:10.1037/1076-8998.6.4.275

Heeger, D. J., & Ress, D. (2004). Neuronal correlates of visual attention and perception. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 339–350). Cambridge, MA: MIT Press.

Heilman, R. M., Crişan, L. G., Houser, D., Miclea, M., & Miu, A. C. (2010). Emotion regulation and decision making under risk and uncertainty. *Emotion*, *10*(2), 257–265. doi:10.1037/a0018489

Heino, A., van der Molen, H. H., & Wilde, G. J. S. (1996). Differences in risk experience between sensation avoiders and sensation seekers. *Personality and Individual Differences*, *20*(1), 71–79. doi:10.1016/0191-8869(95)00152-V

Helleiner, E. (2011). Understanding the 2007–2008 global financial crisis: Lessons for scholars of international political economy. *Annual Review of Political Science*, *14*(1), 67–87. doi:10.1146/annurev-polisci-050409-112539

Hellier, E., Tucker, M., Newbold, L., Edworthy, J., Griffin, J., & Coulson, N. (2012). The effects of label design characteristics on perceptions of genetically modified food. *Journal of Risk Research*, *15*(5), 533–545. doi:10.1080/13669877.2011.646288

Helmreich, R. L. (2000). On error management: Lessons from aviation. *British Medical Journal*, *320*(7237), 781–785.

Hemenway, D. (2009). How to find nothing. *Journal of Public Health Policy*, *30*(3), 260–268. doi:10.1057/jphp.2009.26

Hemenway, D., & Solnick, S. J. (1993). Fuzzy dice, dream cars, and indecent gestures: Correlates of driver behavior. *Accident Analysis & Prevention*, *25*(2), 161–170. doi:10.1016/0001-4575(93)90056-3

Hemingway, M. A., & Smith, C. S. (1999). Organizational climate and occupational stressors as predictors of withdrawal behaviours and injuries in nurses. *Journal of Occupational and Organizational Psychology*, *72*(3), 285–299. doi:10.1348/096317999166680

Henderson, L. A., & Macefield, V. G. (2013). Functional imaging of the human brainstem during somatosensory input and autonomic output. *Frontiers in Human Neuroscience*, *7*, 569. doi:10.3389/fnhum.2013.00569

Hendruks, A. A. J. (1997). *The construction of the Five-Factor Personality Inventory (FFPI)*. Groningen, the Netherlands: University of Groningen Press.

Herbert, B. M., Muth, E. R., Pollatos, O., & Herbert, C. (2012). Interoception across modalities: On the relationship between cardiac awareness and the sensitivity for gastric functions. *PLoS One*, *7*(5), e36646. doi:10.1371/journal.pone.0036646

Hermelin, E., & Robertson, I. T. (2001). A critique and standardization of meta-analytic validity coefficients in personnel selection. *Journal of Occupational and Organizational Psychology*, *74*(3), 253–278. doi:10.1348/096317901167352

Heron, J., Aaen-Stockdale, C., Hotchkiss, J., Roach, N. W., McGraw, P. V., & Whitaker, D. (2012). Duration channels mediate human time perception. *Proceedings of The Royal Society B*, *279*(1729), 690–698. doi:10.1098/rspb.2011.1131

Hersey, P., & Blanchard, K. H. (1982). Leadership style: Attitudes and behaviors. *Training & Development Journal*, *36*(5), 50–52.

Hesketh, B., & Robertson, I. T. (1993). Validating personnel selection: A process model for research and practice. *International Journal of Selection and Assessment*, *1*(1), 3–17. doi:10.1111/j.1468-2389.1993.tb00079.x

Hesse, C., Lane, A. R., Aimola, L., & Schenk, T. (2012). Pathways involved in human conscious vision contribute to obstacle-avoidance behaviour. *European Journal of Neuroscience*, *36*(3), 2383–2390. doi:10.1111/j.1460-9568.2012.08131.x

Hewlett, S., & Luce, C. (2006). Extreme jobs: The dangerous allure of the 70-hour work week. *Harvard Business Review*, *84*(12), 49–59.

Hickman, J. S., & Geller, E. S. (2003a). Self–management to increase safe driving among short–haul truck drivers. *Journal of Organizational Behavior Management*, *23*(4), 1–20. doi:10.1300/J075v23n04_01

Hickman, J. S., & Geller, E. S. (2003b). A safety self–management intervention for mining operations. *Journal of Safety Research*, *34*(3), 299–308. doi:10.1016/S0022-4375(03)00032-X

Hidden, A. (1989). *Investigation into the Clapham Junction railway accident*. London, UK: HMSO.

Hietanen, M. A., Crowder, N. A., & Ibbotson, M. R. (2008). Differential changes in human perception of speed due to motion adaptation. *Journal of Vision*, *8*(11), 6. doi:10.1167/8.11.6

Higgins, E. T. (1997). Beyond pleasure and pain. *American Psychologist*, *52*(12), 1280–1300. doi:10.1037/0003-066X.52.12.1280

Hildebrandt, F., Benzing, T., & Katsanis, N. (2011). Ciliopathies. *New England Journal of Medicine*, *364*(16), 1533–1543. doi:10.1056/NEJMra1010172

Hills, R. (2001, July/August). Sensing for danger. *Science Technology Report*. https://www.llnl.gov/str/JulAug01/Hills.html.

Hoang, N., Schleicher, E., Kacprzak, S., Bouly, J-P., Picot, M., Wu, W., … Ahmad, M. (2008). Human and *Drosophila* cryptochromes are light activated by flavin photoreduction in living cells. *PLoS Biology*, *6*(7), e160. doi:10.1371/journal.pbio.0060160

Hobfoll, S. E. (1989). Conservation of resources: A new attempt at conceptualizing stress. *The American Psychologist*, *44*(3), 513–524. doi:10.1037/0003-066X.44.3.513

Hobfoll, S. E. (2002). Social and psychological resources and adaptation. *Review of General Psychology*, *6*(4), 307–324. doi:10.1037/1089-2680.6.4.307

Hockey, G. R. J., Clough, P. J., & Maule, A. I. (1996, September). *Effects of emotional state on decision making and risk behavior*. Presented at the Risk and Human Behavior (Economic and Social Research Council) Conference, York, UK.

Hoffmeister, K., Gibbons, A. M., Johnson, S. K., Cigularov, K. P., Chen, P. Y., & Rosecrance, J. C. (2014). The differential effects of transformational leadership facets on employee safety. *Safety Science*, *62*, 68–78. doi:10.1016/j.ssci.2013.07.004

Hofmann, D. A., Jacobs, R., & Landy, F. (1995). High reliability process industries: Individual, micro, and macro organizational influences on safety performance. *Journal of Safety Research*, *26*(3), 131–149. doi:10.1016/0022-4375(95)00011-E

Hofmann, D. A., & Morgeson, F. P. (1999). Safety-related behavior as a social exchange: The role of perceived organizational support and leader–member exchange. *Journal of Applied Psychology*, *84*(2), 286–296. doi:10.1037/0021-9010.84.2.286

Hofmann, D. A., Morgeson, F. P., & Gerras, S. J. (2003). Climate as a moderator of the relationship between leader-member exchange and content specific citizenship: Safety climate as an exemplar. *Journal of Applied Psychology*, *88*(1), 170–178. doi:10.1037/0021-9010.88.1.170

Hofmann, D. A., & Stetzer, A. (1996). A cross-level investigation of factors influencing unsafe behaviors and accidents. *Personnel Psychology*, *49*(2), 307–339. doi:10.1111/j.1744-6570.1996.tb01802.x

Hofmann, D. A., & Stetzer, A. (1998). The role of safety climate and communication in accident interpretation: Implications for learning from negative events. *The Academy of Management Journal*, *41*(6), 644–657. doi:10.2307/256962

Hofstede, G. R. (1991). *Cultures and organizations: Software of the mind*. London, UK: McGraw-Hill.

Hofstede, G. R. (1994). *Cultures and organizations: Software of the mind* (2nd ed.). New York, NY: Harper Collins.

Hogan, J., & Foster, J. (2013). Multifaceted personality predictors of workplace safety performance: More than conscientiousness. *Human Performance*, *26*(1), 20–43. doi:10.1080/08959285.2012.736899

Hogan, J., & Rybicki, S. L. (1998). *Performance improvement characteristics job analysis*. Tulsa, OK: Hogan Assessment Systems.

Holcom, M. L., Lehman, W. E. K., & Simpson, D. D. (1993). Employee accidents: Influences of personal characteristics, job characteristics, and substance use in jobs differing in accident potential. *Journal of Safety Research*, *24*(4), 205–211. doi:10.1016/0022-4375(93)80002-S

Holland, K., Blood, R. W., Imison, M., Chapman, S., & Fogerty, A. (2012). Risk, expert uncertainty, and Australian news media: Public and private faces of expert opinion during the 2009 swine flu pandemic. *Journal of Risk Research*, *15*(6), 657–671. doi:10.1080/13669877.2011.652651

Holmes, T. H., & Rahe, R. (1967). The social readjustment rating scale. *Journal of Psychosomatic Research*, *11*(2), 213–218. doi:10.1016/0022-3999(67)90010-4

Hopfinger, J. B., Luck, S. J., & Hillyard, S. A. (2004). Selective attention: Electrophysiological and neuromagnetic studies. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 561–574). Cambridge, MA: MIT Press.

Hopfl, H. (1994). Safety culture, corporate: Organizational transformation and the commitment to safety. *Disaster Prevention and Management*, *3*(3), 49–58.

Hopkins, A. (2000). *Lessons from Longford: The ESSO Gas Plant Explosion*. Sydney, New South Wales, Australia: CCH Australia.

Hopkins, A. (2005). *Safety, culture and risk: The organizational causes of disasters*. Sydney, New South Wales, Australia: CCH Australia.

Hopkins, A. (2008). *Failure to learn: The BP Texas City refinery disaster*. Sydney, New South Wales: CCH Australia.

Hopkins, A. (2012). *Disastrous decisions: The human and organisational causes of the Gulf of Mexico blow-out*. Sydney, New South Wales: CCH Australia.

Horowitz, S. S. (2012). *The universal sense: How hearing shapes the mind*. London, UK: Bloomsbury.

Horvath, J., Forte, J., & Carter, O. (2015). Quantitative review finds no evidence of cognitive effects in healthy populations from single-session transcranial direct current stimulation (tDCS). *Brain Stimulation*, *8*(3), 535–550. doi:10.1016/j.brs.2015.01.400

Hoşgör, E., Apt, J., & Fischhoff, B. (2013). Incorporating seismic concerns in site selection for enhanced geothermal power generation. *Journal of Risk Research*, *16*(8), 1021–1036. doi:10.1080/13669877.2013.788058

Hough, L. M. (1992). The 'big five' personality variables—Construct confusion: Description versus prediction. *Human Performance*, *5*(1–2), 139–155. doi:10.1080/08959285.1992.9667929

Houghton, R., Baber, C., Cowton, M., Stanton, N. A., & Walker, G. H. (2008). WESTT (Workload, Error, Situation Awareness, Time and Teamwork): An analytical prototyping system for command and control. *Cognition, Technology and Work*, *10*(3), 199–207. doi:10.1007/s10111-007-0098-4

Hourihan, K. L., Benjamin, A. S., & Liu, X. (2012). A cross-race effect in metamemory: Predictions of face recognition are more accurate for members of our own race. *Journal of Applied Research in Memory and Cognition*, *1*(3), 158–162. doi:10.1016/j.jarmac.2012.06.004

House, R. J. (1977). A 1976 theory of charismatic leadership. In J. G. Hunt & L. L. Larson (Eds.), *Leadership: The cutting edge* (pp. 189–207). Carbondale, IL: Southern Illinois University Press.

House, R. J., & Mitchell, T. R. (1974). Path-goal theory of leadership. *Journal of Contemporary Business*, *3*(4), 81–97.

House, R. J., Spangler, W. D., & Woycke, J. (1991). Personality and charisma in the U.S. presidency: A psychological theory of leader effectiveness. *Administrative Science Quarterly*, *36*(3), 364–396.

Houston, D., & Allt, S. K. (1997). Psychological distress and error making among junior house officers. *British Journal of Health Psychology*, *2*(2), 141–151. doi:10.1111/j.2044-8287.1997.tb00530.x

Hove, T., Paek, H-J., Yun, M., & Jwa, B. (2015). How newspapers represent environmental risk: The case of carcinogenic hazards in South Korea. *Journal of Risk Research*. doi:10.1080/13669877.2014.923025

Howe, M. L., Garner, S. R., & Patel, M. (2013). Positive consequences of false memories. *Behavioral Sciences & the Law*, *31*(5), 652–665. doi:10.1002/bsl.2078

Howell, J. M., & Avolio, B. J. (1992). The ethics of charismatic leadership: Submission or liberation? *The Academy of Management Executive*, *6*(2), 43–54. doi:10.5465/AME.1992.4274395

Hu, Y-x., Wang, D-w., Pang, K-y., Xu, G-x., & Guo, J-h. (2015). The effect of emotion and time pressure on risk decision-making. *Journal of Risk Research*, *18*(5), 637–650. doi:10.1080/13669877.2014.910688

Huang, T. (2012). Toward the NGO-involved schooling: A study on teachers' risk perception and teachings. *Journal of Risk Research*, *15*(9), 1159–1169. doi:10.1080/13669877.2012.713384

Huang, Y., Robertson, M. M., Lee, J., Rineer, J., Murphy, L. A., Garabet, A., & Dainoff, M. J. (2014). Supervisory interpretation of safety climate versus employee safety climate perception: Association with safety behavior and outcomes for lone workers. *Transportation Research Part F: Traffic Psychology and Behavior*, *26*(B), 348–360. doi:10.1016/j.trf.2014.04.006

Huang, Y., Verma, S. K., Chang, W., Courtney, T. K., Lombardi, D. A., Brennan, M. J., & Perry, M. J. (2012). Supervisor vs. employee safety perceptions and association with future injury in U.S. limited-service restaurant workers. *Accident Analysis and Prevention*, *47*, 45–51. doi:10.1016/j.aap.2011.11.023

Huang, Y., Zohar, D., Robertson, M. M., Garabet, A., Lee, J., & Murphy, L. A. (2013). Development and validation of safety climate scales for lone workers using truck drivers as exemplar. *Transportation Research Part F: Traffic Psychology and Behavior*, *17*, 5–19. doi:10.1016/j.trf.2012.08.011

Huang, Y., Zohar, D., Robertson, M. M., Garabet, A., Murphy, L. A., & Lee, J. (2013). Development and validation of safety climate scales for mobile remote workers using utility/electrical workers as exemplar. *Accident Analysis and Prevention*, *59*, 76–86. doi:10.1016/j.aap.2013.04.030

Huang, Y.-H., Chen, P. Y., Krauss, A. D., & Rogers, D. A. (2004). Quality of the execution of corporate safety policies and employee safety outcomes: Assessing the moderating role of supervisor safety support and the mediating role of employee safety control. *Journal of Business and Psychology*, *18*(4), 483–506. doi:10.1023/B:JOBU.0000028448.01394.bf

Huang, Y.-H., Ho, M., Smith, G. S., & Chen, P. Y. (2006). Safety climate and self-reported injury: Assessing the mediating role of employee safety control. *Accident Analysis & Prevention*, *38*(3), 425–433. doi:10.1016/j.aap.2005.07.002

Huber, M., & Rothstein, H. (2013). The risk organisation: Or how organisations reconcile themselves to failure. *Journal of Risk Research*, *16*(6), 651–675. doi:10.1080/13669877.2012.761276

Hudson, P. (2007). Implementing a safety culture in a major multi-national. *Safety Science*, *45*(6), 697–722. doi:10.1016/j.ssci.2007.04.005

Hughes, H. C. (1999). *Sensory exotica: A world beyond human experience*. Cambridge, MA: MIT Press.

Hummel, T., Olgun, S., Gerber, J., Huchel, U., & Frasnelli, J. (2013). Brain responses to odor mixtures with sub-threshold components. *Frontiers in Psychology*, *4*, 796. doi:10.3389/fpsyg.2013.00786

Hummel, T., Springborn, M., Croy, I., Kaiser, J., & Lötsch, J. (2011). High pain sensitivity is distinct from high susceptibility to non-painful sensory input at threshold level. *International Journal of Psychophysiology*, *80*(1), 69–74. doi:10.1016/j.ijpsycho.2011.01.012

Humphreys, G. W., & Samson, D. (2004). Attention and the frontal lobes. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 607–617). Cambridge, MA: MIT Press.

Hunka, A. D., Meli, M., Palmqvist, A., Thorbek, P., & Forbes, V. E. (2015). Ecological risk assessment of pesticides in the EU: What factors and groups influence policy changes? *Journal of Risk Research*. doi:10.1080/13669877.2014.913663

Hymel, P. A., Loeppke, R. R., Baase, C. M., Burton, W. N., Hartenbaum, N. P., Hudson, T. W., … & Larson, P. W. (2011). Workplace health protection and promotion: A new pathway for a healthier—and safer—workforce. *Journal of Occupational and Environmental Medicine*, *53*(6), 695–702. doi:10.1097/JOM.0b013e31822005d0

Iannilli, E., Singh, P. B., Schuster, B., Gerber, J., & Hummel, T. (2012). Taste laterality studied by means of umami and salt stimuli: An fMRI study. *NeuroImage*, *60*(1), 426–435. doi:10.1016/j.neuroimage.2011.12.088

Iaria, G., Bogod, N., Fox, C. J., & Barton, J. J. (2009). Developmental topographical disorientation: Case one. *Neuropsychologia*, *47*(1), 30–40. doi:10.1016/j.neuropsychologia.2008.08.021

Ignjatović, L., & Todorovski, Z. (2010). The relationship between the revised reinforcement theory, the alternative five-factor model of personality and risky behaviors. *Current Top Neurological and Psychiatric Relations Discipline*, *18*(4), 20–27.

Ilgen, D. R. (1999). Teams embedded in organizations: Some implications. *American Psychologist*, *54*, 129–142.

Inness, M., Turner, N., Barling, J., & Stride, C. B. (2010). Transformational leadership and employee safety performance: A within-person, between-jobs design. *Journal of Occupational Health Psychology*, *15*(3), 279–290. doi:10.1037/a0019380

International Atomic Energy Agency. (1986). *Summary report on the post–accident review meeting on the Chernobyl accident* (International Safety Advisory Group, Safety Series 75–INSAG–1). Vienna, Austria: IAEA.

International Civil Aviation Organization. (1993). *Human factors, management, and organization* (Human Factors Digest No. 10). Montreal, Quebec, Canada: ICAO.

International Labor Organization. (1992). *Conditions of Work Digest: Preventing Stress at Work* (Ed. V. Di Martino). Geneva, Switzerland: ILO.

International Nuclear Safety Advisory Group. (1991). *Safety culture*. (Safety series 75–INSAG–4). Vienna, Austria: IAEA.

International Organization for Standardization. (1998). *Ergonomics of the thermal environment—Instruments for measuring physical quantities* (ISO 7726: EN). Geneva, Switzerland: ISO.

International Organization for Standardization. (2001a). *Mechanical vibration—Measurement and evaluation of human exposure to hand-transmitted vibration—Part 1: General requirements* (ISO 5349-1). Geneva, Switzerland: ISO.

International Organization for Standardization. (2001b). *Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration—Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems* (ISO 2631-4). Geneva, Switzerland: ISO.

International Organization for Standardization. (2002). *Mechanical vibration. Measurement and assessment of human exposure to hand-transmitted vibration. Practical guidance for measurement at the workplace* (BS EN ISO 5349-2). Geneva, Switzerland: ISO.

International Organization for Standardization. (2013). *Guidelines for incorporating accessibility in standards* (ISO/IEC JTAG Guide 71 N222, 2nd ed.). Geneva, Switzerland: ISO.

Ioannides, A. A., Liu, L., Poghosyan, V., Saridis, G. A., Gjedde, A., Ptito, M., & Kupers, R. (2013). MEG reveals a fast pathway from somatosensory cortex to occipital areas via posterior parietal cortex in a blind subject. *Frontiers in Human Neuroscience*, *7*, 429. doi:10.3389/fnhum.2013.00429

Irish Medicines Board. (2015). Commentary—Transparency and trust in the European pharmaceutical sector: Outcomes from a qualitative study. *Journal of Risk Research*. doi:10.1080/13669877.2014.923031

Ishikawa, T., & Montello, D. R. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive Psychology*, *52*(2), 93–129. doi:10.1016/j.cogpsych.2005.08.003

Israel, B. A., Baker, E. A., Goldenhar, L. M., Heaney, C. A., & Schurman, S. J. (1996). Occupational stress, safety and health: Conceptual framework and principles for effective prevention interventions. *Journal of Occupational Health Psychology*, *1*(3), 261–286. doi:10.1037/1076-8998.1.3.261

Iversen, H., & Rundmo, T. (2002). Personality, risky driving and accident involvement among Norwegian drivers. *Personality and Individual Differences*, *33*(8), 1251–1263. doi:10.1016/S0191-8869(02)00010-7

Iverson, R. D., & Erwin, P. J. (1997). Predicting occupational injury: The role of affectivity. *Journal of Occupational and Organizational Psychology*, *70*(2), 113–128. doi:10.1111/j.2044-8325.1997.tb00637.x

Iwatsuki, K., & Uneyama, H. (2012). Sense of taste in the gastrointestinal tract. *Journal of Pharmacological Sciences*, *118*(2), 123–128. doi:10.1254/jphs.11RO8CP

Jaccard, J., Dodge, T., & Guilamo-Ramos, V. (2005). Metacognition, risk behavior, and risk outcomes: The role of perceived intelligence and perceived knowledge. *Health Psychology*, *24*(2), 161–170. doi:10.1037/0278-6133.24.2.161

Jackson, D. N., & Rothstein, M. (1993). Evaluating personality testing in personnel selection. *The Psychologist*, *6*, 8–11.

Jackson, S. E., & Schuler, R. S. (1985). A meta-analysis and conceptual critique of research on role ambiguity and role conflict in work settings. *Organizational Behavior and Human Decision Processes*, *36*(1), 16–78. doi:10.1016/0749-5978(85)90020-2

Jacob, R., Winstanley, A., Togher, N., Roche, R., & Mooney, P. (2012). Pedestrian navigation using the sense of touch. *Computers, Environment and Urban Systems*, *36*(6), 513–525. doi:10.1016/j.compenvurbsys.2012.10.001

Jacobs, J., Kahana, M. J., Ekstrom, A. D., Mollison, M. V., & Fried, I. (2010). A sense of direction in human entorhinal cortex. *Proceedings of the National Academy of Sciences*, *107*(14), 6487–6492. doi:10.1073/pnas.0911213107

Jacobs, J., Weidemann, C. T., Miller, J. F., Solway, A., Burke, J. F., Wei, X-X., … Kahana, M. J. (2013). Direct recordings of grid-like neuronal activity in human spatial navigation. *Nature Neuroscience*, *16*(9), 1188–1190. doi:10.1038/nn.3466

Jacobs, J. A., & Gerson, K. (2004). *The time divide: Work, family, and gender inequality*. Cambridge, MA: Harvard University Press.

Jager, A. D. (2004). Mass murder in Australia. *Current Opinion in Psychiatry*, *17*(5), 407–409. doi:10.1097/01.yco.0000139979.68060.13

James, L. R., Demaree, R. G., Mulaik, S. A., & Ladd, R. T. (1992). Validity generalization in the context of situational models. *Journal of Applied Psychology*, *77*(1), 3–14. doi:10.1037/0021-9010.77.1.3

James, L. R., & Jones, A. P. (1974). Organizational climate: A review of theory and research. *Psychological Bulletin*, *81*(12), 1096–1112. doi:10.1037/h0037511

Jäncke, L., Rogenmoser, L., Meyer, M., & Elmer, S. (2012). Pre-attentive modulation of brain responses to tones in coloured-hearing synesthetes. *BMC Neuroscience*, *13*(1), 151–166. doi:10.1186/1471-2202-13-151

Janicak, C. A. (1996). Predicting accidents at work with measures of locus of control and job hazards. *Psychological Reports*, *78*(1), 115–121. doi:10.2466/pr0.1996.78.1.115

Janis, I. L. (1972). *Victims of group think: A psychological study of foreign policy decisions and fiascos.* Boston, MA: Houghton & Mifflin.

Janis, I. L., & Mann, L. (1977). *Decision-making: A psychological analysis of conflict, choice and commitment*. New York, NY: Free Press.

Janssens, M., Brett, J. M., & Smith, F. J. (1995). Confirmatory cross–cultural research: Testing the viability of a corporation–wide safety policy. *Academy of Management Journal*, *38*(2), 364–382. doi:10.2307/256684

Jehn, K. A. (1995). A multimethod examination of the benefits and detriments of intragroup conflict. *Administrative Science Quarterly*, *40*(2), 256–282.

Jenkins, C., Zyzanski, S., & Rosenman, R. (1971). Progress toward validation of a computer-scored test for the Type A coronary-prone behavior pattern. *Psychosomatic Medicine*, *33*(3), 193–202.

Jensen, J. L., Ponsaing, C. D., & Thrane, S. (2012). Risk resources and structures: Experimental evidence of a new cost of risk component—The structural risk component and implications for enterprise risk management. *Risk Management: A Journal of Risk, Crisis and Disaster, 14*(2), 152–175. doi:10.1057/rm.2012.2

Jex, S. M., & Beehr, T. A. (1991). Emerging theoretical and methodological issues in the study of work-related stress. *Research in Personnel and Human Resources Management, 9*(1), 11–365.

Jha, A. (2014). Dynamics of legal regime on safety of nuclear power plants in India after Fukushima disaster. *Journal of Risk Research*, *17*(1), 145–160. doi:10.1080/13669877.2013.841736

Jha, V. (2014). International investment treaty implications for the Indian position on nuclear liability. *Journal of Risk Research*, *17*(1), 81–95. doi:10.1080/13669877.2013.822919

Jia, W.-z., Bandodkar, A. J., Valdés-Ramírez, G., Windmiller, J. R., Yang, Z.-j., Ramirez, J., … Wang, J. (2013). Electrochemical tattoo biosensors for real-time noninvasive lactate monitoring in human perspiration. *Analytical Chemistry*, *85*(14), 6553–6560. doi:10.1021/ac401573r

Jiang, L., Yu, G., Li, Y., & Li, F. (2010). Perceived colleagues' safety knowledge/behavior and safety performance: Safety climate as a moderator in a multilevel study. *Accident Analysis & Prevention*, *42*(5), 1468–1476. doi:10.1016/j.aap.2009.08.017

Johansen, J. P., Cain, C. K., Ostroff, L. E., & LeDoux, J. E. (2011). Molecular mechanisms of fear learning and memory. *Cell*, *147*(3), 509–524. doi:10.1016/j.cell.2011.10.009

Johansen, J. P., Hamanaka, H., Monfils, M. H., Behnia, R., Deisseroth, K., Blair, H. T., & LeDoux, J. E. (2010). Optical activation of lateral amygdala pyramidal cells instructs associative fear learning. *Proceedings of the National Academy of Sciences*, *107*(28), 12692–12697. doi:10.1073/pnas.100248107

Johansen, J. P., Tarpley, J. W., LeDoux, J. E., & Blair, H. T. (2010). Neural substrates for expectatiomn-modulated fear learning the the amygdala and periaqueductal gray. *Nature Neuroscience*, *13*(8), 979–988. doi:10.1038/nn.2594

Johansen, J. P., Wolff, S. B. E., Lüthi, A., & LeDoux, J. E. (2012). Controlling the elements: An optogenetic approach to understanding the neural circuits of fear. *Biological Psychiatry*, *71*(12), 1053–1060. doi:10.1016/j.biopsych.2011.10.023

Johns, G. (2006). The essential impact of context on organizational behavior. *Academy of Management Review*, *31*(2), 386–408. doi:10.5465/AMR.2006.20208687

Johnson, D. D. P., Blumstein, D. T., Fowler, J. H., & Haselton, M. G. (2013). The evolution of error: Error management, cognitive constraints, and adaptive decision-making biases. *Trends in Ecology & Evolution*, *28*(8), 474–481. doi:10.1016/j.tree.2013.05.014

Johnson, D. D. P., & Fowler, J. H. (2011). The evolution of overconfidence. *Nature*, *477*(7364), 317–320. doi:10.1038/nature10384

Johnson, D. D. P., & Fowler, J. H. (2013). Complexity and simplicity in the evolution of decision-making biases. *Trends in Ecology & Evolution*, *28*(8), 446–447. doi:10.1016/j.tree.2013.06.003

Johnson, J. V., Hall, E. M., & Theorell, T. (1989). Combined effects of job strain and social isolation on cardiovascular disease morbidity and mortality in a random sample of the Swedish male working population. *Scandinavian Journal of Work Environment and Health*, *15*(4), 271–279.

Johnson, K. A., & Becker, J. A. (1995–1999). *The Whole Brain Atlas*. http://www.med.harvard.edu/aanlib/home.html. Accessed June 24, 2015.

Johnson, R. E., Rosen, C. C., & Levy, P. E. (2008). Getting to the core of self-evaluation: A review and recommendations. *Journal of Organizational Behavior*, *29*(3), 391–413. doi:10.1002/job.514

Johnson, S. E. (2007). The predictive validity of safety climate. *Journal of Safety Research*, *38*(5), 511–521. doi:10.1016/j.jsr.2007.07.001

Johnson, S. E., & Hall, A. (2005). The prediction of safe lifting behavior: An application of the theory of planned behavior. *Journal of Safety Research*, *36*(1), 63–73. doi:10.1016/j.jsr.2004.12.004

Jonah, B. A. (1997). Sensation seeking and risk driving: A review and synthesis of the literature. *Accident Analysis & Prevention*, *29*(5), 651–665. doi:10.1016/S0001-4575(97)00017-1

Jonah, B. A., Thiessen, R., & Au-Yeung, E. (2001). Sensation seeking, risky driving and behavioural adaptation. *Accident Analysis & Prevention*, *33*(5), 679–684. doi:10.1016/S0001-4575(00)00085-3

Jonah, B. A., & Wilson, R. J. (1986). Impaired drivers who have never been caught: Are they different from convicted impaired drivers? (SAE Technical Paper Series No. 860195). SAE International. doi:10.4271/860195

Jondle, D., Maines, T. D., Burke, M. R., & Young, P. (2013). Modern risk management through the lens of the ethical organizational culture. *Risk Management: A Journal of Risk, Crisis and Disaster*, *15*(1), 32–49. doi:10.1057/rm.2012.11

Jones, F., Conner, M., McMillan, B., & Ferguson, E. (2007). Impact of daily mood, work hours, and iso-strain variables on self-reported health behaviors. *Journal of Applied Psychology*, *92*(6), 1731–1740. doi:10.1037/0021-9010.92.6.1731

Jones, J. W., & Wuebker, L. J. (1993). Safety locus of control and employees' accidents. *Journal of Business and Psychology*, *7*(4), 449–457. doi:10.1007/BF01013758

Jones, P. E., & Roelofsma, P. H. M. P. (2000). The potential for social contextual and group biases in team decision-making: Biases, conditions and psychological mechanisms. *Ergonomics*, *43*(8), 1129–1152. doi:10.1080/00140130050084914

Jordan, G., Deeb, S. S., Bosten, J. M., & Mollon J. D. (2010). The dimensionality of color vision in carriers of anomalous trichromacy. *Journal of Vision*, *10*(8), 12. doi:10.1167/10.8.12

Jordan, J., Gurr, E., Tinline, G., Giga, S., Faragher, B., & Cooper, C. (2003). *Beacons of excellence in stress prevention research* (Report 133). London, UK: Health and Safety Executive.

Jovanović, A. S., & Baloš, D. (2013). iNTeg-Risk project: Concept and first results. *Journal of Risk Research*, *16*(3–4), 275–291. doi:10.1080/13669877.2012.729516

Jovanović, A. S., & Pilić, V. (2013). Dealing with risk-risk interdependencies and trade-offs in relation to development and use of new technologies. *Journal of Risk Research*, *16*(3–4), 393–406. doi:10.1080/13669877.2012.729528

Jovanović, A. S., & Renn, O. (2013). Search for the "European way" of taming the risks of new technologies: The EU research project iNTeg-Risk. *Journal of Risk Research*, *16*(3–4), 271–274. doi:10.1080/13669877.2012.743162

Judge, T. A. (1993). Does affective disposition moderate the relationship between job satisfaction and voluntary turnover? *Journal of Applied Psychology*, *78*(3), 395–401. doi:10.1037/0021-9010.78.3.395

Judge, T. A., & Bono, J. E. (2001). Relationship of core self-evaluations traits—self-esteem, generalized self-efficacy, locus of control, and emotional stability—with job satisfaction and job performance: A meta-analysis. *Journal of Applied Psychology*, *86*(1), 80–92. doi:10.1037/0021-9010.86.1.80

Judge, T. A., Bono, J. E., Ilies, R., & Gerhardt, M. W. (2002). Personality and leadership: a qualitative and quantitative review. *Journal of Applied Psychology*, *87*(4), 765–780. doi:10.1037/0021-9010.87.4.765

Judge, T. A., Erez, A., Bono, J. E., & Thoresen, C. J. (2003). The core self-evaluations scale: Development of a measure. *Personnel Psychology*, *56*(2), 303–331. doi:10.1111/j.1744-6570.2003.tb00152.x

Judge, T. A., Locke, E. A., Durham, C. C., & Kluger, A. N. (1998). Dispositional effects on job and life satisfaction: The role of core evaluations. *Journal of Applied Psychology*, *83*(1), 17–34. doi:10.1037/0021-9010.83.1.17

Judge, T. A., Martocchio, J. J., & Thoresen, C. J. (1997). Five-factor model of personality and employee absence. *Journal of Applied Psychology*, *82*(5), 745–755. doi:10.1037/0021-9010.82.5.745

Judge, T. A., & Piccolo, R. F. (2004). Transformational and transactional leadership: A meta-analytic test of their relative validity. *Journal of Applied Psychology*, *89*(5), 755–768. doi:10.1037/0021-9010.89.5.755

Judge, T. A., Piccolo, R. F., & Ilies, R. (2004). The forgotten ones? The validity of consideration and initiating structure in leadership research. *Journal of Applied Psychology*, *89*(1), 36–51. doi:10.1037/0021-9010.89.1.36

Jung, D. I., & Avolio, B. J. (2000). Opening the black box: An experimental investigation of the mediating effects of trust and value congruence on transformational and transactional leadership. *Journal of Organizational Behavior*, *21*(8), 949–964. doi:10.1002/200012.21.8

Jusyte, A., & Schönenberg, M. (2014). Threat processing in generalized social phobia: An investigation of interpretation biases in ambiguous facial affect. *Psychiatry Research*, *217*(1), 100–106. doi:10.1016/j.psychres.2013.12.031

Kahn, R. L., & Byosiere, P. (1992). Stress in organizations. In M. D. Dunnette & L. M. Hough (Eds.), *Handbook of industrial and organizational psychology* (2nd ed., Vol. 3, pp. 571–650). Palo Alto, CA: Consulting Psychologists Press.

Kahneman, D. (2011). *Thinking, fast and slow*. London, UK: Penguin.

Kalimo, R., & Toppinen, S. (1999). Finland: Organizational well-being. Ten years of research and development in a forest industry corporation. In M. Kompier & C. L. Cooper (Eds.), *Preventing stress, improving productivity: European case studies in the workplace* (pp. 52–85). London: Routledge.

Kammeyer-Mueller, J. D., Judge, T. A., & Scott, B. A. (2009). The role of core self-evaluations in the coping process. *Journal of Applied Psychology*, *94*(1), 177–195. doi:10.1037/a0013214

Kang, K., Pulver, S. R., Panzano, V. C., Chang, E. C., Griffith, L. C., Theobald, D. L., & Garrity, P. A. (2010, March 25). Analysis of Drosophila TRPA1 reveals an ancient origin for human chemical nociception. *Nature*, *464*, 597–601. doi:10.1038/nature08848

Kanner, A. D., Coyne, J. C., Schaefer, C., & Lazarus, R. S. (1981). Comparison of two modes of stress measurement: Daily hassles and uplifts versus major life events. *Journal of Behavioral Medicine*, *4*(1), 1–39.

Kaplan, S., Bradley, J. C., Luchman, J. N., & Haynes, D. (2009). On the role of positive and negative affectivity in job performance: A meta-analytic investigation. *Journal of Applied Psychology*, *94*(1), 162–176. doi:10.1037/a0013115

Kapp, E. A. (2012). The influence of supervisor leadership practices and perceived group safety climate on employee safety performance. *Safety Science*, *50*(4), 1119–1124. doi:10.1016/j.ssci.2011.11.011

Kapsimali, M., & Barlow, L. A. (2013). Developing a sense of taste. *Seminars in Cell & Developmental Biology*, *24*(3), 200–209. doi:10.1016/j.semcdb.2012.11.002

Karasek, R. (1979). Job demands, job decision latitude and mental strain: Implications for job redesign. *Administrative Science Quarterly*, *24*(2), 285–308.

Karasek, R. A. (1992). Stress prevention through work reorganization: A summary of 19 international case studies. In V. Di Martino (Ed.), *Conditions of work digest: Preventing stress at work* (pp. 23–41). Geneva, Switzerland: International Labor Organization.

Karasek, R. A., & Theorell, T. (1990). *Healthy work: Stress, productivity, and the reconstruction of working life*. New York, NY: Basic books.

Kark, R., Shamir, B., & Chen, G. (2003). The two faces of transformational leadership: Empowerment and dependency. *Journal of Applied Psychology*, *88*(2), 246–255. doi:10.1037/0021-9010.88.2.246

Karra, E., O'Daly, O. G., Choudhury, A. I., Yousseif, A., Millership, S., Neary, M. T., … Batterham, R. L. (2013). A link between FTO, ghrelin, and impaired brain food-cue responsivity. *The Journal of Clinical Investigation*, *123*(1), 1–13. doi:10.1172/JCI44403

Kastenberg, W. E. (2015). Ethics, risk, and safety culture: Reflections on Fukushima and beyond. *Journal of Risk Research*, *18*(3), 304–316. doi:10.1080/13669877.2014.896399

Kath, L. M., Marks, K. M., & Ranney, J. (2010). Safety climate dimensions, leader-member exchange, and organizational support as predictors of upward safety communication in a sample of rail industry workers. *Safety Science*, *48*(5), 643–650. doi:10.1016/j.ssci.2010.01.016

Katz-Navon, T., Naveh, E., & Stern, Z. (2009). Active learning: When is more better? The case of resident physicians' medical errors. *Journal of Applied Psychology*, *94*(5), 1200–1209. doi:10.1037/a0015979

Kawakami, N., Araki, S., Kawashima, M., Masamuto, T., & Hayashi, T. (1997). Effects of work-related stress reduction on depressive symptoms among Japanese blue-collar workers. *Scandinavian Journal of Work Environment and Health*, *23*(1), 54–59.

Keehn, J. D. (1961). Accident tendency, avoidance learning and perceptual defence. *Australian Journal of Psychology*, *13*(2), 157–169. doi:10.1080/00049536108255999

Keil Centre. (2002). *Evaluating the effectiveness of the Health and Safety Executive's health and safety climate survey tool*. Sudbury, England: HSE Books.

Keller, R. T. (1989). A test of the path–goal theory of leadership, with the need for clarity as a moderator in research and development organizations. *Journal of Applied Psychology*, *74*(2), 208–212. doi:10.1037/0021-9010.74.2.208

Kelloway, E. K., & Barling, J. (2010). Leadership development as an intervention in occupational health psychology. *Work & Stress*, *24*(3), 260–279. doi:10.1080/02678373.2010.518441

Kelloway, E. K., Mullen, J., & Francis, L. (2006). Divergent effects of transformational and passive leadership on employee safety. *Journal of Occupational Health Psychology*, *11*(1), 76–86. doi:10.1037/1076-8998.11.1.76

Kelly, F. R. (1996, July). Worker psychology and safety attitudes. *Professional Safety*, pp. 14–17.

Kelman, H. C. (1958). Compliance, identification and internalisation: Three processes of attitude change. *Journal of Conflict Resolution*, *2*(1), 51–60.

Kerr, S., & Jermier, J. M. (1978). Substitutes for leadership: Their meaning and measurement. *Organizational Behavior and Human Performance*, *22*(3), 375–403. doi:10.1016/0030-5073(78)90023-5

Kheifets, I., Ahlbom, A., Crespi, C. M., Draper, G., Hagihara, J., Lowenthal, R. M., … Filho, V. W. (2010). Pooled analysis of recent studies on magnetic fields and childhood leukaemia. *British Journal of Cancer*, *103*(7), 1128–1135. doi:10.1038/sj.bjc.6605838

Kidwell, R. E., Mossholder, K. W., & Bennett, N. (1997). Cohesiveness and organizational citizenship behavior: A multilevel analysis using work groups and individuals. *Journal of Management*, *23*(6), 775–793. doi:10.1177/014920639702300605

Kiecolt-Glaser, J. K., Fisher, B. S., Ogrocki, P., Stout, J. C., Speicher, C. E., & Glaser, R. (1987). Marital quality, marital disruption, and immune function. *Psychosomatic Medicine*, *49*(1), 13–33.

Kievik, M., ter Huurne, E. F. J., & Gutteling, J. M. (2012). The action suited to the word? Use of the framework of risk information seeking to understand risk-related behaviors. *Journal of Risk Research*, *15*(2), 131–147. doi:10.1080/13669877.2011.601318

Kim, E-s. (2012). Technocratic precautionary principle: Korean risk governance of mad cow disease. *Journal of Risk Research*, *15*(9), 1075–1100. doi:10.1080/13669877.2012.670131

Kim, E-s. (2014). How did enterprise risk management first appear in the Korean public sector? *Journal of Risk Research*, *17*(2), 263–279. doi:10.1080/13669877.2013.808685

Kim, J., & Bie, B. (2013). A dangerous neighbour: The news frames of the radiation effects from the Fukushima nuclear accident. *Risk Management: A Journal of Risk, Crisis and Disaster*, *15*(3), 180–198. doi:10.1057/rm.2013.4

Kim, J., & Oh, S. S. (2014). The virtuous circle in disaster recovery: Who returns and stays in town after disaster evacuation? *Journal of Risk Research*, *17*(5), 665–682. doi:10.1080/13669877.2013.822917

Kim, J., & Oh, S. S. (2015). Confidence, knowledge, and compliance with emergency evacuation. *Journal of Risk Research*, *18*(1), 111–126. doi:10.1080/13669877.2014.880728

Kim, P. H. (1997). When what you know can hurt you: A study of experiential effects on group discussion and performance. *Organizational Behavior and Human Decision Processes*, *69*(2), 165–177.

Kines, P., Andersen, L. P. S., Spangenberg, S., Mikkelsen, K. L., Dyreborg, J., & Zohar, D. (2010). Improving construction site safety through leader-based verbal safety communication. *Journal of Safety Research*, *41*(5), 399–406. doi:10.1016/j.jsr.2010.06.005

Kingsolver, B. (1995). *High tide in Tucson: Essays from now or never*. New York, NY: Harper Collins.

Kinicki, A. J., McKee, F. M., & Wade, K. J. (1996). Annual review 1991–1995: Occupational health. *Journal of Vocational Behavior*, *49*(2), 190–220. doi:10.1006/jvbe.1996.0040

Kirkcaldy, B., Furnham, A., & Shepard, R. (2009). The impact of working hours and working patterns on physical and psychological health. In S. Cartwright & C. L. Cooper (Eds.), *The Oxford handbook of organizational well-being* (pp. 303–330). Oxford, UK: Oxford University Press.

Kirkcaldy, B. D., Trimpop, R., & Cooper, C. L. (1997). Working hours, job stress, work satisfaction and accident rates among medical practitioners, consultants and allied personnel. *International Journal of Stress Management*, *4*(2), 79–87. doi:10.1007/BF02765302

Kirkpatrick, S. A., & Locke, E. A. (1991). A trait approach to the study of leadership in small groups. *Academy of Management Executive*, *5*(5), 48–60.

Kirkpatrick, S. A., & Locke, E. A. (1996). Direct and indirect effects of three core charismatic leadership components on performance and attitudes. *Journal of Applied Psychology*, *81*(1), 36–51. doi:10.1037/0021-9010.81.1.36

Kisch, E. S. (1985). Stressful events and the onset of diabetes mellitus. *Israel Journal of Medical Sciences*, *21*(4), 356–358.

Kishimoto, A. (2013). Redefining safety in the era of risk trade-off and sustainability. *Journal of Risk Research*, *16*(3–4), 369–377. doi:10.1080/13669877.2012.729527

Kjellén, U., & Baneryd, K. (1983). Changing local health and safety practices at work within the explosives industry. *Ergonomics*, *26*(9), 863–877. doi:10.1080/00140138308963414

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man and Cybernetics*, *19*(3), 462–472.

Klein, R. (2004). Orienting and inhibition of return. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 545–559). Cambridge, MA: MIT Press.

Klein, S. B. (2004). The cognitive neuroscience of knowing one's self. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1077–1089). Cambridge, MA: MIT Press.

Klein, T. A., Endrass, T., Kathmann, N., Neumann, J., Von Cramon, D. Y., & Ullsperger, M. (2007). Neural correlates of error awareness. *Neuroimage*, *34*(4), 1774–1781. doi:10.1016/j.neuroimage.2006.11.014

Klein, T. A., Ullsperger, M., & Danielmeier, C. (2013). Error awareness and the insula: Links to neurological and psychiatric diseases. *Frontiers in Human Neuroscience*, *7*, 14. doi:10.3389/fnhum.2013.00014

Klemm, C., Das, E., & Hartmann, T. (2015). Swine flu and hype: A systematic review of media dramatization of the H1N1 influenza pandemic. *Journal of Risk Research*. doi:10.1080/13669877.2014.923029

Klima, K., & Morgan, M. G. (2012). Thoughts on whether government should steer a tropical cyclone if it could. *Journal of Risk Research*, *15*(8), 1013–1020. doi:10.1080/13669877.2012.686054

Klima, N. (2012). Temporal dimensions of vulnerability to crime in economic sectors: Theory meets evidence and spawns a new framework. *Risk Management: A Journal of Risk, Crisis and Disaster*, *14*(2), 93–108. doi:10.1057/rm.2011.7

Klinke, A., & Renn, O. (2012). Adaptive and integrative governance on risk and uncertainty. *Journal of Risk Research*, *15*(3), 273–292. doi:10.1080/13669877.2011.636838

Kluckholn, C. M., & Murray, H. A. (1953). Personality formation: Its determinants. In C. M. Kluckholn & H. A. Murray (Eds.), *Personality in nature, society and* culture (2nd ed., pp. 55–67). New York, NY: Knopf.

Knapper, C. K., Copley, A. J., & Moore, R. J. (1976). Attitudinal factors in the non–use of seat belts. *Accident Analysis and Prevention*, *8*(4), 241–246.

Knight, R. T., & Grabowecky, M. (2000). Prefrontal cortex, time, and consciousness. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1319–1339). Cambridge, MA: MIT Press.

Knoch, D., Gianotti, L. R. R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., & Brugger, P. (2006). Disruption of right prefrontal cortex by low-frequency repetitive transcranial magnetic stimulation induces risk-taking behavior. *The Journal of Neuroscience*, *26*(24), 6469–6472. doi:10.1523/JNEUROSCI.0804-06.2006

Knuth, D., Kehl, D., Galea, E., Hulse, L., Sans, J., Vallès, L., … Schmidt, S. (2014). BeSeCu-S—A self-report instrument for emergency survivors. *Journal of Risk Research*, *17*(5), 601–620. doi:10.1080/13669877.2013.815649

Knuth, D., Kehl, D., Hulse, L., Spangenberg, L., Brähler, E., & Schmidt, S. (2015). Risk perception and emergency experience: Comparing a representative German sample with German emergency survivors. *Journal of Risk Research*, *18*(5), 581–601. doi:10.1080/13669877.2014.910685

Kobal, G., & Hummel, T. (1991). Human electro-olfactograms and brain responses to olfactory stimulation. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 135–151). Berlin, Germany: Springer.

Koçak, M. (2012). Threat assessment of terrorist organizations: The application of Q methodology. *Journal of Risk Research*, *15*(1), 85–105. doi:10.1080/13669877.2011.601323

Koch, M. (1999). The neurobiology of startle. *Progress in Neurobiology*, *59*(2), 107–128. doi:10.1016/S0301-0082(98)00098-7

Koehne, B., Shih, P. C., & Olson, J. S. (2012). Remote and alone: Coping with being the remote member on the team. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work* (pp. 1257–1266). ACM.

Koelega, H. S. (1992). Extraversion and vigilance: 30 years of inconsistencies. *Psychological Bulletin*, *112*(2), 239–258. doi:10.1037/0033-2909.112.2.239

Koletsou, A., & Mancy, R. (2011). Which efficacy constructs for large-scale social dilemma problems? Individual and collective forms of efficacy and outcome expectancies in the context of climate change mitigation. *Risk Management: An International Journal*, *13*(4), 184–208. doi:10.1057/rm.2011.12

Kompier, M., & Cooper, C. L. (1999). Stress prevention: European countries and European cases compared. In M. Kompier & C. L. Cooper (Eds.), *Preventing stress, improving productivity: European case studies in the workplace* (pp. 312–336). London, UK: Routledge.

Kompier, M. A. J. (1996). Job design and well-being. In M. J. Schabracq, J. A. M. Winnubst, & C. L. Cooper (Eds.), *Handbook of work and health psychology* (pp. 349–368). New York, NY: Wiley.

Köster, E. P., Møller, P., & Mojet, J. (2014). A "misfit" theory of spontaneous conscious odor perception (MITSCOP): Reflections on the role and function of odor memory in everyday life. *Frontiers in Psychology*, *5*, 64. doi:10.3389/fpsyg.2014.00064

Kozlowski, S. W. J., & Klein, K. J. (2000). A multilevel approach to theory and research in organizations: Contextual, temporal, and emergent processes. In K. J. Klein & S. W. J. Kozlowski (Eds.), *Multilevel theory, research, and methods in organizations: Foundations, extensions and new directions* (pp. 3–90). San Francisco, CA: Jossey-Bass.

Krausmann, E., & Baranzini, D. (2012). Natech risk reduction in the European Union. *Journal of Risk Research*, *15*(8), 1027–1047. doi:10.1080/13669877.2012.666761

Kretch, K., & Adolph, K. (2013). No bridge too high: Infants decide whether to cross based on the probability of falling not the severity of the potential fall. *Developmental Science*, *16*(3), 336–351. doi:10.1111/desc.12045

Krewski, D., Turner, M. C., Lemyre, L., & Lee, J. E. C. (2012). Expert vs. public perceptions of population health risks in Canada. *Journal of Risk Research*, *15*(6), 601–625. doi:10.1080/13669877.2011.649297

Kriegeskorte, N., Simmons, W. K., Bellgowan, P. S., & Baker, C. I. (2009). Circular analysis in systems neuroscience: The dangers of double dipping. *Nature Neuroscience*, *12*(5), 535–540. doi:10.1038/nn.2303

Kringen, J. (2014). Liability, blame, and causation in Norwegian risk regulation. *Journal of Risk Research*, *17*(6), 765–779. doi:10.1080/13669877.2014.889203

Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology*, *77*(6), 1121–1134.

Kumar, A. V. (2014). India's nuclear energy renaissance: Stuck in the middle? *Journal of Risk Research*, *17*(1), 43–60. doi:10.1080/13669877.2013.822921

Kumar, M., & Gregory, M. (2013). An exploration of risk management in global industrial investment. *Risk Management: A Journal of Risk, Crisis and Disaster*, *15*(4), 272–300. doi:10.1057/rm.2013.8

Kunce, J. T. (1967). Vocational interests and accident proneness. *Journal of Applied Psychology*, *51*(3), 223–225. doi:10.1037/h0024685

Kunreuther, H., Meyer, R., & Michel-Kerjan, E. (2013). Overcoming decision biases to reduce losses from natural catastrophes. In E. Shafir (Ed.), *The behavioral foundations of public policy* (pp. 398–416). Princeton, NJ: Princeton University Press.

Kunreuther, H., & Michel-Kerjan, E. (2013). Managing catastrophic risks through redesigned insurance: Challenges and opportunities. In G. Dionne (Ed.), *Handbook of Insurance* (pp. 517–546). New York, NY: Springer.

Kunzle, B., Zala-Mezo, E., Wacker, J., Kolbe, M., Spahn, D. R., & Grote, G. (2010). Leadership in anaesthesia teams: The most effective leadership is shared. *Quality & Safety in Healthcare*, *19*, 1–6. doi:10.1136/qshc.2008.030262

Kuo, C-C., & Tsaur, C-C. (2004). Locus of control, supervisory support and unsafe behavior: The case of construction industry in Taiwan. *Chinese Journal of Psychology*, *46*(4), 293–305.

Kvarnstrom, S. (1996). From Taylorism to 1000 objective-oriented groups: Experiences of a cultural revolution in an industrial concern. In C. L. Cooper, P. Liukkonen, & S. Cartwright (Eds.), *Stress prevention in the workplace: Assessing the costs and benefits to organizations* (pp. 12–25). Dublin, Ireland: European Foundation for the Improvement of Living and Working Conditions.

Kwan, M., & Seah, A. S. T. (2013). Music therapy as a non-pharmacological adjunct to pain management: Experiencers at an acute hospital in Singapore. *Progress in Palliative Care*, *21*(3), 151–157. doi:10.1179/1743291X12Y.0000000042

Labar, K. S., & LeDoux, J. E. (2001). Coping with danger: The neural basis of defensive behaviour and fearful feelings. In B. S. McEwan (Ed.), *Handbook of physiology, the endocrine system, coping with the environment: Neural and endocrine mechanisms* (pp. 139–154). Online publication—Comprehensive physiology. doi:10.1002/cphy.cp070408

Lacina, B., & Gleditsch, N. P. (2005). Monitoring trends in global combat: A new dataset of battle deaths. *European Journal of Population*, *21*(2–3), 145–166. doi:10.1007/s10680-005-6851-6

Lackner, J. R., & Dizio, P. (2004). Multisensory influences on orientation and movement control. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 409–423). Cambridge, MA: MIT Press.

Laing, D. G. (1991). Characteristics of the human sense of smell when processing odor mixtures. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 241–259). Berlin, Germany: Springer.

Laing, D. G., Doty, R. L., & Briepohl, W. (Eds.) (1991). *The human sense of smell*. Berlin, Germany: Springer.

Laing, J. (2001). Extreme G. *Australasian Science*, *22*(6), 23–25.

Lajunen, T. (2001). Personality and accident liability: Are extraversion, neuroticism and psychoticism related to traffic and occupational fatalities? *Personality and Individual Differences*, *31*(8), 1365–1373. doi:10.1016/S0191-8869(00)00230-0

Lajunen, T., & Parker, D. (2001). Are aggressive people aggressive drivers? A study of the relationship between self-reported general aggressiveness, driver anger and aggressive driving. *Accident Analysis & Prevention*, *33*(2), 243–255. doi:10.1016/S0001-4575(00)00039-7

Lamme, V. A. F. (2006). Towards a true neural stance on consciousness. *Trends in Cognitive Sciences*, *10*(11), 494–501. doi:10.1016/j.tics.2006.09.001

Lamme, V. A. F. (2010). How neuroscience will change our view on consciousness. *Cognitive Neuroscience*, *1*(3), 204–240. doi:10.1080/17588921003731586

Lamme, V. A. F., & Landman, R. (2001). Attention sheds no light on the origin of phenomenal experience. *Behavioral and Brain Sciences*, *24*(5), 993–993. doi:10.1017/S140525X01000115

Landström, C., & Bergmans, A. (2015). Long-term repository governance: A socio-technical challenge. *Journal of Risk Research*, 18(3), 378–391. doi:10.1080/13669877.2014.913658

Langham, M., Hole, G., Edwards, J., & O'Neil, C. (2002). An analysis of 'looked but failed to see' accidents involving parked police cars. *Ergonomics*, *45*(3), 167–185. doi:10.1080/00140130110115363

LaPorte, T. R. (1996). High reliability organizations: Unlikely, demanding and at risk. *Journal of Contingencies and Crisis Management*, *4*(2), 60–71. doi:10.1111/j.1468-5973.1996.tb00078.x

LaPorte, T. R., & Consolini, P. M. (1991). Working in practice but not in theory: Theoretical challenges of "high-reliability organizations". *Journal of Public Administration Research and Theory*, *1*(1), 19–48.

Lappe, C., Steinsträter, O., & Pantev, C. (2013). Rhythmic and melodic deviations in musical sequences recruit different cortical areas for mismatch detection. *Frontiers in Human Neuroscience*, *7*, 260. doi:10.3389/fnhum.2013.00260

Lardent, C. L. (1991). Pilots who crash: Personality constructs underlying accident prone behavior of fighter pilots. *Multivariate Experimental Clinical Research*, *10*(1), 1–25.

Larock, S., & Baxter, J. (2013). Local facility hazard risk controversy and non-local hazard risk perception. *Journal of Risk Research*, *16*(6), 713–732. doi:10.1080/13669877.2012.737821

Larsson, G., Setterlind, S., & Starrin, B. (1990). Routinization of stress control programmes in organizations: A study of Swedish teachers. *Health Promotion International*, *5*(4), 269–278. doi:10.1093/heapro/5.4.269

Larson, G. E., Alderton, D. L., Neideffer, M., & Underhill, E. (1997). Further evidence on dimensionality and correlates of the Cognitive Failures Questionnaire. *British Journal of Psychology*, *88*(1), 29–38. doi:10.1111/j.2044-8295.1997.tb02618.x

Larson, G. E., & Merritt, C. R. (1991). Can accidents be predicted? An empirical test of the Cognitive Failures Questionnaire. *Applied Psychology: An International Review*, *40*(1), 37–45. doi:10.1111/j.1464-0597.1991.tb01356.x

Larsson, M., Grunnesjö, E., & Bergström, J. (2012). What counts as a reasonable extent? A systems approach for understanding fire safety in Sweden. *Journal of Risk Research*, *15*(5), 517–532. doi:10.1080/13669877.2011.643478

Latané, B., & Darley, J. (1968). Group inhibition of bystander intervention in emergencies. *Journal of Personality and Social Psychology*, *10*(4 Part 1), 215–221. doi:10.1037/h0025589

Lawless, H. (1991). Effects of odors on mood and behavior: Aromatherapy and related effects. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 361–386). Berlin, Germany: Springer.

Lawrence, P. R., & Lorsch, J. W. (1969). *Developing Organizations: Diagnosis and Action*. Reading, MA: Addison-Wesley.

Lawrie, M., Parker, D., & Hudson, P. (2006). Investigating employee perceptions of a framework of safety culture maturity. *Safety Science*, *44*, 259–276. doi:10.1016/j.ssci.2005.10.003

Lawton, R., & Parker, D. (1998). Individual differences in accident liability: A review and integrative approach. *Human Factors*, *40*(4), 655–671. doi:10.1518/001872098779649292

Lazarus, R. S., & Folkman, S. (1991). The concept of coping. In A. Monat & R. S Lazarus (Eds.), *Stress and coping: An anthology* (3rd ed., pp. 189–206). New York, NY: Columbia University Press.

Leach, D. L., Wall, T. D., Rogelberg, S. G., & Jackson, P. R. (2005). Team autonomy, performance, and member job strain: Uncovering the teamwork KSA link. *Applied Psychology: An International Review*, *54*(1), 1–24. doi:10.1111/j.1464-0597.2005.00193.x

Leana, C. R. (1985). A partial test of Janis's groupthink model: Effects of group cohesiveness and leader behaviour on defective decision making. *Journal of Management*, *11*(1), 5–17. doi:10.1177/014920638501100102

LeDoux, J. E. (2012). Evolution of human emotion: A view through fear. *Progress in Brain Research*, *195*, 431–442. doi:10.1016/B978-0-444-53860-4.00021-0

LeDoux, J. E. (2013). The slippery slope of fear. *Trends in Cognitive Science*, *17*(4), 155–156. doi:10.1016/j.tics.2013.02.004

Lee, E. W. J., Ho, S. S., Chow, J. K., Wu, Y. Y., & Yang, Z-x. (2013). Communication and knowledge as motivators: Understanding Singaporean women's perceived risks of breast cancer and intentions to engage in preventive measures. *Journal of Risk Research*, *16*(7), 879–902. doi:10.1080/13669877.2012.761264

Lee, J. E., & Gleeson, J. G. (2011). A systems-biology approach to understanding the ciliopathy disorders. *Genome Medicine*, *3*(9), 59–68. doi:10.1186/gm275

Lee, R. T., & Ashforth, B. E. (1996). A meta-analytic examination of the correlates of the three dimensions of job burnout. *Journal of Applied Psychology, 81*(2), 123–133. doi:10.1037/0021-9010.81.2.123

Lee, T. R. (1998). Assessment of safety culture at a nuclear reprocessing plan. *Work & Stress, 12*(3), 217–237. doi:10.1080/02678379808256863

Leedom, D. K., & Simon, S. R. (1995). Improving team coordination: A case for behavior-based training. *Military Psychology, 7*(2), 109–122. doi:10.1207/s15327876mp0702_5

Lees, S., & Ellis, N. (1990). The design of a stress-management programme for nursing personnel. *Journal of Advanced Nursing, 15*(8), 946–961. doi:10.1111/j.1365-2648.1990.tb01951.x

Legagneux, P., & Ducatez, S. (2013). European birds adjust their flight initiation distance to road speed limits. *Biology Letters, 9*(5), 20130417. doi:10.1098/rsbl.2013.0417

Legrand, D., & Ruby, P. (2009). What is self-specific? Theoretical investigation and critical review of neuroimaging results. *Psychological Review, 116*(1), 252–282. doi:10.1037/a0014172

Legree, P. J., Heffner, T. S., Psotka, J., Medsker, G. J., & Martin, D. E. (2003). Traffic crash involvement: Experiential driving knowledge and stressful contextual antecedents. *Journal of Applied Psychology, 88*(1), 15–26. doi:10.1037/0021-9010.88.1.15

Lehtveer, M., & Hedenus, F. (2015). Nuclear power as a climate mitigation strategy—Technology and proliferation risk. *Journal of Risk Research, 18*(3), 273–290. doi:10.1080/13669877.2014. 889194

Leighton, T. G., Chua, G. H., White, P. R., Tong, K. F., Griffiths, H. D., & Daniels, D. J. (2013). Radar clutter suppression and target discrimination using twin inverted pulses. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science, 469*(2160), 20130512. doi:10.1098/rspa.2013.0512

Leiter, M. P., Zanaletti, W., & Argentero, P. (2009). Occupational risk perception, safety training, and injury prevention: Testing a model in the Italian printing industry. *Journal of Occupational Health Psychology, 14*(1), 1–10. doi:10.1037/1076-8998.14.1.1

Leonard, C., Fanning, N., Attwood, J., & Buckley, M. (1998). The effect of fatigue, sleep deprivation and onerous working hours on the physical and mental well-being of pre-registration house officers. *Irish Journal of Medical Science, 167*(1), 22–25.

LePine, J. A., Podsakoff, N. P., & LePine, M. A. (2005). A meta-analytic test of the challenge stressor–hindrance stressor framework: An explanation for inconsistent relationships among stressors and performance. *The Academy of Management Journal, 48*(5), 764–775. doi:10.5465/AMJ.2005.18803921

LePine, J. A., & Van Dyne, L. (2001). Peer responses to low performers: An attributional model of helping in the context of groups. *Academy of Management Review, 26*(1), 67–84. doi:10.5465/AMR.2001.4011953

Leppälä, J., Murtonen, M., & Kauranen, I. (2012). Farm risk maps: A contextual tool for risk identification and sustainable management on farms. *Risk Management: A Journal of Risk, Crisis and Disaster, 14*(1), 42–59. doi:10.1057/rm.2011.14

Lerena, P., Auerkari, P., Knaust, C., Vela, I., & Krause, U. (2013). Approaches towards a generic methodology for storage of hazardous energy carriers and waste products. *Journal of Risk Research, 16*(3–4), 433–445. doi:10.1080/13669877.2012.729524

Lerner, J. S., & Keltner, D. (2000). Beyond valence: Toward a model of emotion-specific influences on judgment and choice. *Cognition and Emotion, 14*(4), 473–493. doi:10.1080/026999300402763

Lerner, J. S., & Keltner, D. (2001). Fear, anger, and risk. *Journal of Personality and Social Psychology, 81*(1), 146–159. doi:10.1037/0022-3514.81.1.146

Leroy, H., Dierynck, B., Anseel, F., Simons, T., Halbesleben, J. R. B., McCaughey, D., … Sels, L. (2012). Behavioral integrity for safety, priority of safety, psychological safety, and patient safety: A team-level study. *Journal of Applied Psychology, 97*(6), 1273–1281. doi:10.1037/a0030076

LeShan, L. L. (1952). Dynamics of accident-prone behavior. *Psychiatry, 15*(1), 73–80. doi:10.1521/0033 2747.1952.11022859

Leventhall, G. (2007). What is infrasound? *Progress in Biophysics and Molecular Biology, 93*(1), 130–137. doi:10.1016/j.pbiomolbio.2006.07.006

Levin, I. P., McElroy, T., Gaeth, G. J., Hedgcock, W., & Denburg, N. L. (2014). Behavioral and neuroscience methods for studying neuroeconomic processes: What we can learn from framing effects. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 43–69). Washington, DC: American Psychological Association. doi:10.1037/14322-003

Levine, E. S. (2012). Improving risk matrices: The advantages of logarithmically scaled axes. *Journal of Risk Research*, *15*(2), 209–222. doi:10.1080/13669877.2011.634514

Lewin, K. (1958). Group decision and social change. In E. E. Maccoby, T. M. Newcombe, & R. L. Hartley (Eds.), *Readings in social psychology* (3rd ed., pp. 197–211). New York, NY: Holt.

Lewis, D.-M. (2014). The risk factor: (Re-)visiting adult offender risk assessments within criminal justice practice. *Risk Management: A Journal of Risk, Crisis and Disaster, 16*(2), 121–136. doi:10.1057/rm.2014.6

Lewkowicz, D. J., & Kraebel, K. S. (2004). The value of multisensory redundancy in the development of intersensory perception. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 655–678). Cambridge, MA: MIT Press.

Li, J-g., Tian, M-q., Fang, H-z., Xu, M., Li, H., & Liu, J. (2010). Extraversion predicts individual differences in face recognition. *Communicative & Integrative Biology*, *3*(4), 295–298. PMC2928302

Li, W.-C., & Greaves, M. (2014). Pilots in automated cockpits: A causal factor in accidents or the last line of defence? *The Ergonomist, 523,* 16–18.

Lichtman, R. J, & Lane, I. M. (1983). Effects of group norms and goal setting on productivity. *Group & Organization Studies*, *8*(4), 406–420. doi:10.1177/105960118300800403

Lickliter, R., & Bahrick, L. E. (2004). Perceptual development and the origins of multisensory responsiveness. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 643–654). Cambridge, MA: MIT Press.

Liden, R. C., & Antonakis, J. (2009). Considering context in psychological leadership research. *Human Relations*, *62*(11), 1587–1605. doi:10.1177/0018726709346374

Liden, R. C., Wayne, S. J., & Stilwell, D. (1993). A longitudinal study of the early development of leader–member exchanges. *Journal of Applied Psychology*, *78*(4), 662–674. doi:10.1037/0021-9010.78.4.662

Lieberman, D. E. (2012). What we can learn about running from barefoot running: An evolutionary medical perspective. *Exercise and Sport Sciences Reviews*, *40*(2), 63–72. doi:10.1097/JES.0b013e31824ab210

Lim, B., & Klein, K. J. (2006). Team mental models and team performance: a field study of the effects of team mental model similarity and accuracy. *Journal of Organizational Behavior*, *27*(4), 403–418. doi:10.1002/job.387

Lin, J. Y., Murray, S. O., & Boynton, G. M. (2009). Capture of attention to threatening stimuli without perceptual awareness. *Current Biology*, *19*(13), 1118–1122. doi:10.1016/j.cub.2009.05.021

Lingard, H. C., Cooke, T., & Blismas, N. (2009). Group-level safety climate in the Australian construction industry: Within-group homogeneity and between-group differences in road construction and maintenance. *Construction Management and Economics*, *27*(4), 419–432. doi:10.1080/01446190902822971

Lingard, H. C., Cooke, T., & Blismas, N. (2010). Properties of group safety climate in construction: the development and evaluation of a typology. *Construction Management and Economics*, *28*(8), 1099–1112. doi:10.1080/01446193.2010.501807

Linke, S., Gilek, M., Karlsson, M., & Udovyk, O. (2014). Unravelling science-policy interactions in environmental risk governance of the Baltic Sea: Comparing fisheries and eutrophication. *Journal of Risk Research*, *17*(4), 505–523. doi:10.1080/13669877.2013.794154

Litmanen, T., Solomon, B. D., & Kari, K. (2014). The utmost ends of the nuclear fuel cycle: Finnish perceptions of the risks of uranium mining and nuclear waste management. *Journal of Risk Research*, *17*(8), 1037–1059. doi:10.1080/13669877.2013.841727

Lloyd, D., Morrison, I., & Roberts, N. (2006). Role for human posterior parietal cortex in visual processing of aversive objects in peripersonal space. *Journal of Neurophysiology*, *95*(1), 205–214. doi:10.1152/jn.00614.2005

LoBue, V. (2014). Measuring attentional biases for threat in children and adults. *Journal of Visualized Experiments*, *92*, e52190. doi:10.3791/52190

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin*, *127*(2), 267–286. doi:10.1037//0033-2909.127.2.267

Löfquist, L. (2015). After Fukushima: Nuclear power and societal choice. *Journal of Risk Research*, *18*(3), 291–303. doi:10.1080/13669877.2013.841730

Löfstedt, R. (2014a). The substitution principle in chemical regulation: A constructive critique. *Journal of Risk Research*, *17*(5), 543–564. doi:10.1080/13669877.2013.841733

Löfstedt, R. (2014b). A possible way forward for evidence-based and risk-informed policy-making in Europe: A personal view. *Journal of Risk Research*, *17*(9), 1089–1108. doi:10.1080/13669877.2014.919518

Löfstedt, R., & Way, D. (2015). Transparency and trust in the European pharmaceutical sector: Outcomes from an experimental study. *Journal of Risk Research*. doi:10.1080/13669877.2014.919517

Loftus, E. F. (1980). Impact of expert psychological testimony on the unreliability of eyewitness identification. *Journal of Applied Psychology*, *65*(1), 9–15. doi:10.1037/0021-9010.65.1.9

Loftus, E. F., Miller, D. G., & Burns, H. J. (1978). Semantic integration of verbal information into a visual memory. *Journal of Experimental Psychology: Human Learning and Memory*, *4*(1), 19–31. doi:10.1037/0278-7393.4.1.19

Longley, J., & Pruitt, D. G. (1980). Groupthink: A critique of Janis's theory. In L. Wheeler (Ed.), *Review of personality and social psychology* (pp. 507–513). Newbury Park, CA: Sage.

Loo, R. (1979). Role of primary personality factors in the perception of traffic signs and driver violations and accidents. *Accident Analysis & Prevention*, *11*(2), 125–127. doi:10.1016/0001-4575(79)90020-4

Lord, R. G., De Vader, C. L., & Alliger, G. M. (1986). A meta-analysis of the relationship between personality traits and leadership perceptions: An application of validity generalization procedures. *Journal of Applied Psychology*, *71*(3), 402–410. doi:10.1037/0021-9010.71.3.402

Lotze, M. (2013). Kinesthetic imagery of musical performance. *Frontiers in Human Neuroscience*, *7*, 280. doi:10.3389/fnhum.2013.00280

Lourijsen, E., Houtman, I., Kompier, M., & Grundemann, R. (1999). The Netherlands: A hospital, 'healthy working for health'. In M. Kompier & C. L. Cooper (Eds.), *Preventing stress, improving productivity: European case studies in the workplace* (pp. 86–120). London, UK: Routledge.

Lowe, K. B., Kroeck, K. G., & Sivasubramaniam, N. (1996). Effectiveness correlates of transformational and transactional leadership: A meta-analytic review of the MLQ literature. *The Leadership Quarterly*, *7*(3), 385–425. doi:10.1016/S1048-9843(96)90027-2

Lu, T.-F. (2013). Indoor odour source localisation using robot: Initial location and surge distance matter? *Robotics and Autonomous Systems*, *61*(6), 637–647. doi:10.1016/j.robot.2013.02.002

Lu, X., Xie, X-f., & Xiong, J. (2015). Social trust and risk perception of genetically modified food in urban areas of China: The role of salient value similarity. *Journal of Risk Research*, *18*(2), 199–214. doi:10.1080/13669877.2014.889195

Lucarelli, C., Uberti, P., & Brighetti, G. (2015). Misclassifications in financial risk tolerance. *Journal of Risk Research*, *18*(4), 467–482. doi:10.1080/13669877.2014.910678

Lüdtke, O., Roberts, B. W., Trautwein, U., & Nagy, G. (2011). A random walk down university avenue: Life paths, life events, and personality trait change at the transition to university life. *Journal of Personality and Social Psychology*, *101*(3), 620–637. doi:10.1037/a0023743

Luna, B., Padmanabhan, A., & Geier, C. (2014). The adolescent sensation-seeking period: Development of reward processing and its effects on cognitive control. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 93–121). Washington, DC: American Psychological Association. doi:10.1037/14322-005

Lundström, J. N., Boesveldt, S., & Albrecht, J. (2011). Central processing of the chemical senses: An overview. *ACS Chemical Neuroscience*, *2*(1), 5–16. doi:10.1021/cn1000843

Lundström, J. N., Gordon, A. R., Wise, P., & Frasnelli, J. (2012). Individual differences in the chemical senses: Is there a common sensitivity? *Chemical Senses*, *37*(4), 371–378. doi:10.1093/chemse/bjr114

Luo, G-L. (2014). A research and defects analysis of the disaster relief system of China. *Journal of Risk Research*, *17*(3), 383–404. doi:10.1080/13669877.2013.815651

Lupton, T. (1963). *On the shop floor*. Oxford, UK: Pergamon.

Luria, G. (2008). Climate strength—How leaders form consensus. *The Leadership Quarterly*, *19*(1), 42–53. doi:10.1016/j.leaqua.2007.12.004

Luria, G. (2010). The social aspects of safety management: Trust and safety climate. *Accident Analysis and Prevention*, *42*(4), 1288–1295. doi:10.1016/j.aap.2010.02.006

Luria, G., & Morag, I. (2012). Safety management by walking around (SMBWA): A safety intervention program based on both peer and manager participation. *Accident Analysis & Prevention*, *45*, 248–257. doi:10.1016/j.aap.2011.07.010

Luria, G., & Rafaeli, A. (2008). Testing safety commitment in organizations through interpretations of safety artifacts. *Journal of Safety Research*, *39*(5), 519–528. doi:10.1016/j.jsr.2008.08.004

Luria, G., Zohar, D., & Erev, I. (2008). The effect of workers' visibility on effectiveness of intervention programs: Supervisory-based safety interventions. *Journal of Safety Research*, *39*(3), 273–280. doi:10.1016/j.jsr.2007.12.003

Luthans, F., & Avolio, B. J. (2003). Authentic leadership: A positive developmental approach. In K. S. Cameron, J. E. Dutton, & R. E. Quinn (Eds.), *Positive organizational scholarship* (pp. 241–261). San Francisco, CA: Barrett-Koehler.

Luthans, F., Avolio, B. J., Avey, J. B., & Norman, S. M. (2007). Positive psychological capital: Measurement and relationship with performance and satisfaction. *Personnel Psychology*, *60*(3), 541–572. doi:10.1111/j.1744-6570.2007.00083.x

Lynch, B. M., Dunstan, D. W., Vallance, J. K., & Owen, N. (2013). Don't take cancer sitting down: A new survivorship research agenda. *Cancer*, *119*(11), 1928–1935. doi:10.1002/cncr.28028

Macaluso, E., & Driver, J. (2004). Functional imaging evidence for multisensory spatial representations and cross-modal attentional interactions in the human brain. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 529–548). Cambridge, MA: MIT Press.

Machin, M. A., & Sankey, K. S. (2008). Relationships between young drivers' personality characteristics, risk perceptions, and driving behavior. *Accident Analysis & Prevention*, *40*(2), 541–547. doi:10.1016/j.aap.2007.08.010

Macpherson, F. (2010). Individuating the senses. In F. Macpherson (Ed.) *The senses: Classic and contemporary philosophical readings* (pp. 2–72). Oxford, UK: Oxford University Press.

Macy, B. A., & Izumi, H. (1993). Organizational change, design and work innovation: A meta–analysis of 131 North American field studies—1961–1991. *Research in organizational change and design* (Vol. 7). Greenwich, CT: JAI Press.

Mahler, J. G. (2009). *Organizational learning at NASA: The Challenger and Columbia accidents*. Washington, DC: Georgetown University Press.

Mahmoudi, H., Renn, O., Hoffmann, V., Van Passel, S., & Azadi, H. (2015). Social risk screening using a socio-political ambiguity approach: The case of organic agriculture in Iran. *Journal of Risk Research*, *18*(6), 747–770. doi:10.1080/13669877.2014.910696

Maidhof, C. (2013). Error monitoring in musicians. *Frontiers in Human Neuroscience*, *7*, 401. doi:10.3389/fnhum.2013.00401

Mann, R. E., Vinglis, E. R., Anglin, L., Suurvalil, H., Poudrier, L. M., & Vaga, K. (1987). Long-term follow up of convicted drinking drivers. In P. C. Noordzij & R. Roszbach (Eds.), *Alcohol, drugs and traffic safety T86*. *Proceedings of the 10th International Conference on Alcohol, Drugs and Traffic Safety*. Amsterdam, the Netherlands: International Committee on Alcohol, Drugs and Traffic Safety.

Manstead, A. S. R., & Parker, D. (1995). Evaluating and Extending the Theory of Planned Behaviour. *European Review of Social Psychology*, *6*(1), 69–95. doi:10.1080/14792779443000012

Manz, C. C., & Angle, H. (1996). Can group self–management mean a loss of personal control: Triangulating a paradox. *Group and Organization Studies*, *11*(4), 309–334. doi:10.1177/0364108286114002

Manz, C. C., & Neck, C. P. (1995). Teamthink: Beyond the groupthink syndrome. *Journal of Managerial Psychology*, *10*, 7–15. doi:10.1108/13527599710171255

Manz, C. C., & Sims, H. P. Jr. (1980). Self-management as a substitute for leadership: A social learning theory perspective. *The Academy of Management Review*, *5*(3), 361–367. doi:10.5465/AMR.1980.4288845

Marchant, G. E. (2014). 'Soft Law' mechanisms for nanotechnology: Liability and insurance drivers. *Journal of Risk Research*, *17*(6), 709–719. doi:10.1080/13669877.2014.889200

Mark, D. (2005). The sampling of aerosols: Principles and methods. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 185–207). Oxford, UK: Blackwell.

Marks, L. E. (2004). Cross-modal interactions in speeded classification. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 85–105). Cambridge, MA: MIT Press.

Marks, M. A., Sabella, M. J., Burke, C. S., & Zaccaro, S. J. (2002). The impact of cross-training on team effectiveness. *Journal of Applied Psychology*, *87*(1), 3–13. doi:10.1037/0021-9010.87.1.3

Marshall, J. A. R., Trimmer, P. C., & Houston, A. I. (2013). Unbiased individuals use valuable information when making decisions: A reply to Johnson and Fowler. *Trends in Ecology & Evolution*, *28*(8), 444–445. doi:10.1016/j.tree.2013.06.005

Marshall, J. A. R., Trimmer, P. C., Houston, A. I., & McNamara, J. M. (2013). On evolutionary explanations of cognitive biases. *Trends in Ecology & Evolution*, *28*(8), 469–473. doi:10.1016/j.tree.2013.05.013

Martinez, M. G., Verbruggen, P., & Fearne, A. (2013). Risk-based approaches to food safety regulation: What role for co-regulation? *Journal of Risk Research*, *16*(9), 1101–1121. doi:10.1080/13669877.2012.743157

Martínez-Córcoles, M., Gracia, F. J., Tomás, I., & Peiró, J. M. (2011). Leadership and employees' perceived safety behaviors in a nuclear power plant: A structural equation model. *Safety Science*, *49*(8–9), 1118–1129. doi:10.1016/j.ssci.2011.03.002

Martínez-Córcoles, M., Gracia, F. J., Tomás, I., Peiró, J. M., & Schöbel, M. (2013). Empowering team leadership and safety performance in nuclear power plants: A multilevel approach. *Safety Science*, *51*(1), 293–301. doi:10.1016/j.ssci.2012.08.001

Martínez-Córcoles, M., Schöbel, M., Gracia, F. J., Tomás, I., & Peiró, J. M. (2012). Linking empowering leadership to safety participation in nuclear power plants: A structural equation model. *Journal of Safety Research*, *43*(3), 215–221. doi:10.1016/j.jsr.2012.07.002

Marx, B. P., Forsyth, J. P., Gallup, G. G., & Fusé, T. (2008). Tonic immobility as an evolved predator defense: Implications for sexual assault survivors. *Clinical Psychology: Science and Practice*, *15*(1), 74–90. doi:10.1111/j.1468-2850.2008.00112.x

Maslach, C., Schaufeli, W. B., & Leiter, M. P. (2001). Job burnout. *Annual Review of Psychology*, *52*(1), 397–422. doi:10.1146/annurev.psych.52.1.397

Maslen, S. (2015). Organisational factors for learning in the Australian gas pipeline industry. *Journal of Risk Research*, *18(7)*, 896–909. doi:10.1080/13669877.2014.919514

Mateevitsi, V., Haggadone, B., Leigh, J., Kunzer, B., & Kenyon, R. V. (2013, March). Sensing the environment through SpiderSense. In *Proceedings of the 4th Augmented Human International Conference* (pp. 51–57). New York, NY: ACM. doi:10.1145/2459236.2459246

Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Salas, E., & Cannon–Bowers, J. A. (2000). The influence of shared mental models on team processes and performance. *Journal of Applied Psychology*, *85*(2), 272–283. doi:10.1037/0021-9010.85.2.273

Mathieu, J. E., Rapp, T. L., Maynard, M. T., & Mangos, P. M. (2009). Interactive effects of team and task shared mental models as related to air traffic controllers' collective efficacy and effectiveness. *Human Performance*, *23*(1), 22–40. doi:10.1080/08959280903400150

Matrajt, M. (1992). Using ergonomic analysis and group discussion to identify and prevent stress in managers and assembly-line workers. *Conditions of Work Digest*, *11*(2), 152–163.

Matthews, G., & Desmond, P. A. (2001). Stress and driving performance: Implications for design and training. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload and fatigue: Theory, research and practice* (pp. 211–231). Mahwah, NJ: Erlbaum.

Matthews, G., Dorn, L., & Glendon, A. I. (1991). Personality correlates of driver stress. *Personality and Individual Differences*, *12*(6), 535–549. doi:10.1016/0191-8869(91)90248-A

Matthews, G., Stanton, N. A., Graham, N. C., & Brimelow, C. (1990). A factor analysis of the scales of the Occupational Personality Questionnaire. *Personality and Individual Differences*, *11*(6), 591–596. doi:10.1016/0191-8869(90)90042-P

Matthews, G., Tsuda, A., Xin, G., & Ozeki, Y. (1999). Individual differences in driver stress vulnerability in a Japanese sample. *Ergonomics*, *42*(3), 401–415. doi:10.1080/001401399185559

Matthews, M. L., & Moran, A. R. (1986). Age differences in male drivers' perception of accident risk: The role of perceived driving ability. *Accident Analysis & Prevention*, *18*(4), 299–313. doi:10.1016/0001-4575(86)90044-8

Matthias, E., Schandry, R., Duschek, S., & Pollatos, O. (2009). On the relationship between interoceptive awareness and the attentional processing of visual stimuli. *International Journal of Psychophysiology*, *72*(2), 154–159. doi:10.1016/j.ijpsycho.2008.12.001

Mauelshagen, C., Denyer, D., Carter, M., & Pollard, S. (2013). Respect for experience and organisational ability to operate in complex and safety critical environments. *Journal of Risk Research*, *16*(9), 1187–1207. doi:10.1080/13669877.2012.761273

Maunsell, J. H. R., & Ghose, G. M. (2004). Dynamics of attentional modulation in visual cerebral cortex. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 351–358). Cambridge, MA: MIT Press.

Mauro, S. E-D. (2012). Minding history and world-scale dynamics in hazards research: The making of hazardous soils in the Gambia and Hungary. *Journal of Risk Research*, *15*(10), 1319–1333. doi: 10.1080/13669877.2012.591500

Mavratzakis, A., Molloy, E., & Walla, P. (2013). Modulation of the startle reflex during brief and sustained exposure to emotional pictures. *Psychology*, *4*(4), 389–395. doi:10.4236/psych.2013.44056

Maxim, L., Mansier, P., & Grabar, N. (2013). Public reception of scientific uncertainty in the endocrine disrupter controversy: The case of male fertility. *Journal of Risk Research*, *16*(6), 677–695. doi:10.1080/13669877.2012.726245

Mayer, D. L., Jones, S. F., & Laughery, K. R. (1987). Accident proneness in the industrial setting. In *Proceedings of the Human Factors Society 31st Annual Meeting* (October 19-22, pp. 196–199). New York.

Mayer, D. M., Aquino, K., Greenbaum, R. L., & Kuenzi, M. (2012). Who displays ethical leadership and why does it matter? An examination of antecedents and consequences of ethical leadership. *The Academy of Management Journal*, *55*(1), 151–171. doi:10.5465/amj.2008.0276

Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An integrative model of organizational trust. *The Academy of Management Review*, *20*(3), 709–734. doi:10.5465/AMR.1995.9508080335

Mayer, R. E., & Treat, J. R. (1977). Psychological, social and cognitive characteristics of high risk drivers: A pilot study. *Accident Analysis & Prevention*, *9*(1), 1–8. doi:10.1016/0001-4575(77)90002-1

McAdams, D. P., & Olson, B. D. (2010). Personality development: Continuity and change over the life course. *Annual Review of Psychology*, *61*(5), 1–5, 26. doi:10.1146/annurev.psych.093008.100507

McCann, K. B., & Sulzer–Azaroff, B. (1996). Cumulative trauma disorders: Behavioral injury control at work. *Journal of Applied Behavioral Science*, *32*(3), 277–291. doi:10.1177/0021886396323003

McCauley, D. P., & Kuhnert, K. W. (1992). A theoretical review and empirical investigation of employee trust in management. *Public Administration Quarterly*, *14*(2), 265–284.

McCrae, R. R., & Costa, P. T. (1985). Updating Norman's "adequate taxonomy": Intelligence and personality dimensions in natural language and in questionnaires. *Journal of Personality and Social Psychology*, *49*(3), 710–721. doi:10.1037/0022-3514.49.3.710

McCrae, R. R., & Costa, P. T. (1987). Validation of the five-factor model of personality across instruments and observers. *Journal of Personality and Social Psychology*, *52*(1), 81–90. doi:10.1037/0022-3514.52.1.81

McCrae, R. R., & Costa, P. T. (1989). More reasons to adopt the five-factor model. *American Psychologist*, *44*(2), 451–452. doi:10.1037/0003-066X.44.2.451

McCright, A. M., & Dunlap, R. E. (2013). Bringing ideology in: The conservative white male effect on worry about environmental problems in the USA. *Journal of Risk Research*, *16*(2), 211–226. doi:10.1080/13669877.2012.726242

McCue, J. D., & Sachs, C. L. (1991). A stress management workshop improves residents' coping skills. *JAMA Internal Medicine*, *151*(11), 2273–2277. doi:10.1001/archinte.1991.00400110117023

McDonald, N., Corrigan, S., Daly, C., & Cromie, S. (2000). Safety management systems and safety culture in aircraft maintenance organizations. *Safety Science*, *34*(1–3), 151–176.

McDonough, P. (2000). Job insecurity and health. *International Journal of Health Services*, *30*(3), 453–476. doi:10.2190/BPFG-X3ME-LHTA-6RPV

McGee, T. K., & Gow, G. A. (2012). Potential responses by on-campus university students to a university emergency alert. *Journal of Risk Research*, *15*(6), 693–710. doi:10.1080/13669877.2011.652653

McGrath, J. E. (1976). Stress and behaviour in organizations. In M. D. Dunnette (Ed.), *Handbook of industrial and organizational psychology*. Chicago, IL: Rand McNally.

McGurk, H., & McDonald, J. W. (1976). Hearing lips and seeing voice. *Nature*, *264*, 746–748. doi:10.1038/264746a0

McInerney, P. A. (2001). *Final Report of the Special Commission of Inquiry into the Glenbrook Rail Accident*. Sydney, Australia: Government of New South Wales.

McInerney, P. A. (2004). *Interim Report of the Special Commission of Inquiry into the Waterfall Rail Accident.* Sydney, Australia: Government of New South Wales.

McInerney, P. A. (2005). *Final Report of the Special Commission of Inquiry into the Waterfall Rail Accident.* Sydney, Australia: Government of New South Wales.

McKay, R., & Efferson, C. (2010). The subtleties of error management. *Evolution and Human Behavior*, *31*(5), 309–319. doi:10.1016/j.evolhumbehav.2010.04.005

McKeefry, D. J., Burton, M. P., Vakrou, C., Barrett, B. T., & Morland, A. B. (2008). Induced deficits in speed perception by transcranial magnetic stimulation of human cortical areas V5/MT and V3A. *The Journal of Neuroscience*, *28*(27), 6848–6857. doi:10.1523/JNEUROSCI.1287-08.2008

McKenna, E. F. (2006). *Business psychology and organisational behaviour* (4th edn.). Hove, UK: Psychology Press.

McKenna, F. P. (1983). Accident proneness: A conceptual analysis. *Accident Analysis & Prevention*, *15*(1), 65–71. doi:10.1016/0001-4575(83)90008-8

McKiernan, F., Houchins, J. A., & Mattes, R. D. (2008). Relationships between human thirst, hunger, drinking, and feeding. *Physiology & Behavior*, *94*(5), 700–708. doi:10.1016/j.physbeh.2008.04.007

McKinley, M. J., Bowala, T., Egan, G. E., Farrell, M. J., Fox, P., Mathai, M. L., … Denton, D. A. (2007). Age-related changes in thirst and associated neural activity in human subjects. *Appetite*, *49*(1), 313. doi:10.1016/j.appet.2007.03.136

McLain, D. L. (1995). Responses to health and safety risk in the work environment. *Academy of Management Journal*, *38*(6), 1726–1743. doi:10.2307/256852

McMillan, T. M., & Rachman, S. J. (1988). Fearlessness and courage in paratroopers undergoing training. *Personality and Individual Differences*, *9*(2), 373–378. doi:10.1016/0191-8869(88)90100-6

McMillen, D. L., Smith, S. M., & Wells-Parker, E. (1989). The effects of alcohol, expectancy, and sensation seeking on driving risk taking. *Addictive Behaviors*, *14*(4), 477–483. doi:10.1016/0306-4603(89)90037-3

Meadows, M. L., Stradling, S. G., & Lawson, S. (1998). The role of social deviance and violations in predicting road traffic accidents in a sample of young offenders. *British Journal of Psychology*, *89*(3), 417–431. doi:10.1111/j.2044-8295.1998.tb02694.x

Mearns, K., Flin, R., Gordon, R., & Fleming, M. (1998). Measuring safety climate on offshore installations. *Work & Stress*, *12*(3), 238–254. doi:10.1080/02678379808256864

Mearns, K., Whittaker, S. M., & Flin, R. (2001). Benchmarking safety climate in hazardous environments: A longitudinal, interorganizational approach. *Risk Analysis*, 21(4), 771–786. doi:10.1111/0272-4332.214149

Mearns, K., Whitaker, S. M., & Flin, R. (2003). Safety climate, safety management practice and safety performance in offshore environments. *Safety Science*, *41*(8), 641–680. doi:10.1016/S0925-7535(02)00011-5

Meier, L. L., Semmer, N. K., Elfering, A., & Jacobshagen, N. (2008). The double meaning of control: Three-way interactions between internal resources, job control, and stressors at work. *Journal of Occupational Health Psychology*, *13*(3), 244–258. doi:10.1037/1076-8998.13.3.244

Meijer, A. (2015). Comment on paper 'Transparency and trust in the European pharmaceutical sector'. *Journal of Risk Research*. doi:10.1080/13669877.2014.923030

Melamed, S., Luz, J., Najenson, T., Jucha, E., & Green, M. (1989). Ergonomic stress levels, personal characteristics, accident occurrence and sickness absence among factory workers. *Ergonomics*, *32*(9), 1101–1110. doi:10.1080/00140138908966877

Melcher, J. R., Knudson, I. M., & Levine, R. A. (2013). Subcallosal brain structure: Correlation with hearing threshold at supra-clinical frequencies (>8 kHz), but not with tinnitus. *Hearing Research*, *295*, 79–86. doi:10.1016/j.heares.2012.03.013

Meliá, J. L., Tomás, J. M., Oliver, A., & Islas, M. E. (1992). *Organizational and psychological variables as antecedents of work safety: A causal model*. Paper presented at the Safety and Well-being at Work Conference, Loughborough, UK, November.

Mennen, M. G., & van Tuyll, M. C. (2015). Dealing with future risks in the Netherlands: The National Security Strategy and the National Risk Assessment. *Journal of Risk Research*, *18(7)*, 860–876. doi:10.1080/13669877.2014.923028

Merabet, L. B., Hamilton, R., Schlaug, G., Swisher, J. D., Kiriakopoulos, E. T., Pitskel, N. B., … Pascual-Leone, A. (2008). Rapid and reversible recruitment of early visual cortex for touch. *PLoS One*, *3*(8), e3046. doi:10.1371/journal.pone.0003046

Merabet, L. B., Swisher, J. D., McMains, S. A., Halko, M. A., Amedi, A., Pascual-Leone, A., & Somers, D. C. (2006). Combined activation and deactivation of visual cortex during tactile sensory processing. *Journal of Neurophysiology*, *97*(2), 1633–1641. doi:10.1152/jn.00806.2006

Merckelbach, H., Muris, P., Nijman, H., & de Jong, P. J. (1996). Self-reported cognitive failures and neurotic symptomatology. *Personality and Individual Differences*, *20*(6), 715–724. doi:10.1016/0191-8869(96)00024-4

Merikle, P. M., & Daneman, M. (2000). Conscious vs. unconscious perception. In Gazzaniga, M. S. (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 1295–1303). Cambridge, MA: MIT Press.

Merritt, A. C., & Helmreich, R. L. (1996). Creating and sustaining a safety culture. *CRM Advocate*, *1*, 8–12.

Merz, M., Hiete, M., Comes, T., & Schultmann, F. (2013). A composite indicator model to assess natural disaster risks in industry on a spatial level. *Journal of Risk Research*, *16*(9), 1077–1099. doi:10.1080/13669877.2012.737820

Mesken, J., Lajunen, T., & Summala, H. (2002). Interpersonal violations, speeding violations and their relation to accident involvement in Finland. *Ergonomics*, *45*(7), 469–483. doi:10.1080/00140130210129682

Metlay, W., & Kaplan, I. T. (1992). *Characteristics and consequences of self-management.* Paper presented at an International Conference on Self-Managed Work Teams, Dallas, TX: University of North Texas.

Meyer, D., Leventhal, H., & Gutmann, M. (1985). Common-sense models of illness: The example of hypertension. *Health Psychology*, *4*(2), 115–135. doi:10.1037/0278-6133.4.2.115

Michael, J. H., Evans, D. D., Jansen, K. J., & Haight, J. M. (2005). Management commitment to safety as organizational support: Relationships with non-safety outcomes in wood manufacturing employees. *Journal of Safety Research*, *36*(2), 171–179. doi:10.1016/j.jsr.2005.03.002

Michaels, C. E., & Spector, P. E. (1982). Causes of employee turnover: A test of the Mobley, Griffeth, Hand, and Meglino model. *Journal of Applied Psychology*, *67*(1), 53–59. doi:10.1037/0021-9010.67.1.53

Michahelles, F., Matter, P., Schmidt, A., & Schiele, B. (2003). Applying wearable sensors to avalanche rescue. *Computers & Graphics*, *27*(6), 839–847. doi:10.1016/j.cag.2003.08.008

Michel-Kerjan, E. (2012). How resilient is your country? Extreme events are on the rise. Governments must implement national risk-management strategies. *Nature*, *491*, 497–497.

Micocci, M., & Ajovalasit, M. (2014). Enhancing human experience using smart materials. *The Ergonomist*, *531*, 4–5.

Miller, A. (2015). Observations on 'Transparency and trust in the European pharmaceutical sector'. *Journal of Risk Research*. doi:10.1080/13669877.2014.940602

Miller, J. D., Campbell, K. W., Young, D. L., Lakey, C. E., Reidy, D. E., Zeichner, A., & Goodie, A. S. (2009). Examining the relations among narcissism, impulsivity, and self-defeating behaviors. *Journal of Personality*, *77*(3), 761–794. doi:10.1111/j.1467-6494.2009.00564.x

Miller, J. D., Lynam, D. R., & Jones, S. (2008). Externalizing behavior through the lens of the five-factor model: A focus on agreeableness and conscientiousness. *Journal of Personality Assessment*, *90*(2), 158–164. doi:10.1080/00223890701845245

Mills, B., Reyna, V. F., & Estrada, S. (2008). Explaining contradictory relations between risk perception and risk taking. *Psychological Science*, *19*(5), 429–433. doi:10.1111/j.1467-9280.2008.02104.x

Milner, A. D., & Goodale, M. A. (2008). Two visual systems re-viewed. *Neuropsychologia*, *46*(3), 774–785. doi:10.1016/j.neuropsychologia.2007.10.005

Miner, J. B., & Brewer, J. F. (1983). The management of ineffective performance. In M. D. Dunnette (Ed.), *Handbook of industrial and organisational psychology* (pp. 995–1029). New York, NY: Wiley.

Mishra, S. (2014). Decision-making under risk: Integrating perspectives from biology, economics, and psychology. *Personality and Social Psychology Review*, *18*(3), 280–307. doi:10.1177/1088868314530517

Mohan M. P. R. (2014). Nuclear liability law of India: An appraisal of extent of liability, right of recourse and transboundary applicability. *Journal of Risk Research*, *17*(1), 115–131. doi:10.1080/13669877.2013.841735

Mohan, M. P. R., & Babu, R. R. (2014). Nuclear energy law and decision-making in India: Editorial. *Journal of Risk Research*, *17*(1), 1–6. doi:10.1080/13669877.2013.849879

Mohan, M. P. R., & Shandilya, A. (2015). Nuclear energy and risk assessment by Indian courts: Analysis of judicial intervention in the Kudankulam Nuclear Power Project. *Journal of Risk Research*, *18(8)*, 1051–1069. doi:10.1080/13669877.2014.913665

Montello, D. R., & Xiao, D. (2011). Linguistic and cultural universality of the concept of sense-of-direction. In M. J. Egenhofer (Ed.), *Spatial information theory* (pp. 264–282). Berlin/Heidelberg, Germany: Springer.

Moore, C. M., Lanagan-Leitzel, L. K., & Fine, E. M. (2008). Distinguishing between the precision of attentional localization and attentional resolution. *Perception & Psychophysics*, *70*(4), 573–582. doi:10.3758/PP.70.4.573

Moorhead, G., Ference, R., & Neck, C. P. (1991). Group think fiascoes continue: Space Shuttle Challenger and a revised groupthink framework. *Human Relations*, *44*(6), 539–550. doi:10.1177/001872679104400601

Moreland, R. L., & Levine, J. M. (2001). Socialization in organizations and work groups. In M. E. Turner (Ed.), *Groups at work: Theory and research* (pp. 69–112). Hillsdale, NJ: Erlbaum.

Moriarty, O., McGuire, B. E., & Finn, D. P. (2011). The effect of pain on cognitive function: A review of clinical and preclinical research. *Progress in Neurobiology*, *93*(3), 385–404. doi:10.1016/j.pneurobio.2011.01.002

Morillon, B., & Barbot, A. (2013). Attention in the temporal domain: A phase-coding mechanism controls the gain of sensory processing. *Frontiers in Human Neuroscience*, *7*, 480. doi:10.3389/fnhum.2013.00480

Morris, J. S., & Dolan, R. J. (2001). Involvement of human amygdala and orbitofrontal cortex in hunger-enhanced memory for food stimuli. *The Journal of Neuroscience*, *21*(14), 5304–5310.

Morrison, E. W. (2014). Employee voice and silence. *Annual Review of Organizational Psychology and Organizational Behavior*, *1*, 173–197. doi:10.1146/annurev-orgpsych-031413-091328

Morrison, E. W., & Milliken, F. J. (2000). Organizational silence: A barrier to change and development in a pluralistic world. *Academy of Management Review*, *25*(4), 706–725. doi:10.5465/AMR.2000.3707697

Morrison, E. W., & Rothman, N. B. (2009). Silence and the dynamics of power. In J. Greenberg & M. Edwards (Eds.), *Voice and silence in organizations* (pp. 175–202). Bingley, UK: Emerald.

Morrison, I., Lloyd, D., Di Pellegrino, G., & Roberts, N. (2004). Vicarious responses to pain in anterior cingulate cortex: Is empathy a multisensory issue? *Cognitive, Affective, & Behavioral Neuroscience*, *4*(2), 270–278. doi:10.3758/CABN.4.2.270

Morrison, I., Peelen, M. V., & Downing, P. E. (2007). The sight of others' pain modulates motor processing in human cingulate cortex. *Cerebral Cortex*, *17*(9), 2214–2222. doi:10.1093/cercor/bhl129

Morrison, I., Poliakoff, E., Gordon, L., & Downing, P. (2007). Response-specific effects of pain observation on motor behavior. *Cognition*, *104*(2), 407–416. doi:10.1016/j.cognition.2006.07.006

Morrow, P. C., & Crum, M. R. (1998). The effects of perceived and objective safety risk on employee outcomes. *Journal of Vocational Behavior*, *53*(2), 300–313. doi:10.1006/jvbe.1997.1620

Moscarello, J. M., & LeDoux, J. E. (2013). The contribution of the amygdala to aversive and appetitive Pavlovian processes. *Emotion Review*, *5*(3), 248–253. doi:10.1177/1754073913477508

Moser, C., Stauffacher, M., Blumer, Y. B., & Scholz, R. W. (2015). From risk to vulnerability: The role of perceived adaptive capacity for the acceptance of contested infrastructure. *Journal of Risk Research*, *18*(5), 622–636. doi:10.1080/13669877.2014.910687

Moser, C., Stauffacher, M., Krütle, & Scholz, R. W. (2012). The influence of linear and cyclical temporal representations on risk perception of nuclear waste: An experimental study. *Journal of Risk Research*, *15*(5), 459–476. doi:10.1080/13669877.2011.636836

Mount, M. K., Barrick, M. R., & Stewart, G. L. (1998). Five-factor model of personality and performance in jobs involving interpersonal interactions. *Human Performance*, *11*(2–3), 145–166. doi:10.1080/08959285.1998.9668029

Mouraviev, N., & Kakabadse, N. K. (2014). Risk allocation in a public–private partnership: A case study of construction and operation of kindergartens in Kazakhstan. *Journal of Risk Research*, *17*(5), 621–640. doi:10.1080/13669877.2013.815650

Mudu, P., & Beck, E. (2012). Navigating scientific routes to risk assessment: A tortuous path. *Journal of Risk Research*, *15*(10), 1217–1222. doi:10.1080/13669877.2012.730227

Mujica-Parodi, L. R., Carlson, J. M., Cha, J., & Rubin, D. (2014). The fine line between 'brave'and 'reckless': Amygdala reactivity and regulation predict recognition of risk. *NeuroImage*, *103*, 1–9. doi:10.1016/j.neuroimage.2014.08.038

Mullen, B., Anthony, T., Salas, E., & Driskell, J. E. (1994). Group cohesiveness and quality of decision making: An integration of tests of the groupthink hypothesis. *Small Group Research*, 25(2), 189–204. doi:10.1177/1046496494252003

Mullen, J. (2005). Testing a model of employee willingness to raise safety issues. *Canadian Journal of Behavioural Sciences*, *37*(4), 273–282. doi:10.1037/h0087262

Mullen, J., Kelloway, E. K., & Teed, M. (2011). Inconsistent style of leadership as a predictor of safety behaviour. *Work & Stress*, *25*(1), 41–54. doi:10.1080/02678373.2011.569200

Mullen, J. E., & Kelloway, E. K. (2009). Safety leadership: A longitudinal study of the effects of transformational leadership on safety outcomes. *Journal of Occupational and Organizational Psychology*, *82*(2), 253–272. doi:10.1348/096317908X325313

Munipov, V. M. (1991). Human engineering analysis of the Chernobyl accident. In M. Kumashiro & E. D. Megaw (Eds.), *Towards human work: Solutions to problems in occupational health and safety* (pp. 380–386). London, UK: Taylor & Francis.

Munz, D. C., Kohler, J. M., & Greenberg, C. I. (2001). Effectiveness of a comprehensive worksite stress management program: Combining organizational and individual interventions. *International Journal of Stress Management*, *8*(1), 49–62.

Murendo, C., Keil, A., & Zeller, M. (2011). Drought impacts and related risk management by smallholder farmers in developing countries: Evidence from Awash River Basin, Ethiopia. *Risk Management: An International Journal*, *13*(4), 247–263. doi:10.1057/rm.2011.17

Murphy, L. R. (1988). Workplace interventions for stress reduction and prevention. In C. L. Cooper & R. Payne (Eds.), *Causes, coping and consequences of stress at work* (pp. 301–339). New York, NY: Wiley.

Murphy, L. R., DuBois, D., & Hurrell, J. J. (1986). Accident reduction through stress management. *Journal of Business and Psychology*, *1*(1), 5–18.

Nabi, H., Consoli, S. M., Chastang, J-F., Chiron, M., Lafont, S., & Lagarde, E. (2005). Type A behavior pattern, risky driving behaviors, and serious road traffic accidents: A prospective study of the GAZEL cohort. *American Journal of Epidemiology*, *161*(9), 864–870. doi:10.1093/aje/kwi110

Nachreiner, F., & Hänecke, K. (1992). Vigilance. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance Vol. 3: State and trait* (pp. 261–288). London, UK: Academic Press.

Nachtmann, H., & Pohl, E. A. (2013). Emergency medical services via inland waterways. *Risk Management: A Journal of Risk, Crisis and Disaster*, *15*(4), 225–249. doi:10.1057/rm.2013.6

Nahrgang, J. D., Morgeson, F. P., & Hofmann, D. A. (2011). Safety at work: A meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes. *Journal of Applied Psychology*, *96*(1), 71–94. doi:10.1037/a0021484

Naime, A., & Andrey, J. (2013). Improving risk-based regulatory processes: Identifying measures to pursue risk-informed regulation. *Journal of Risk Research*, *16*(9), 1141–1161. doi:10.1080/13669877.2012.761265

Nakanishi, H. (2015). Japan-India civil nuclear energy cooperation: Prospects and concerns. *Journal of Risk Research*, *18(8)*, 1083–1098. doi:10.1080/13669877.2014.913666

Nakanishi, M., & Yamamoto, S. (2011). Applicability of touch sense controllers using warm and cold sensations. In M. J. Smith & G. Salvendy (Eds.), *Human Interface, Part I* (pp. 470–477). Berlin/Heidelberg, Germany: Springer.

Nakayachi, K., Yokoyama, H. M., & Oki, S. (2015). Public anxiety after the 2011 Tohoku earthquake: Fluctuations in hazard perception after catastrophe. *Journal of Risk Research*, *18*(2), 156–169. doi:10.1080/13669877.2013.875936

Nakayama, K., Maljkovic, V., & Kristjansson, A. (2004). Short-term memory for the rapid deployment of visual attention. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 397–408). Cambridge, MA: MIT Press.

Namer, B., & Reeh, P. (2013). Scratching an itch: Nociceptors respond to both painful and itchy stimuli. MrgprA3-expressing neurons have now been found that are sparsely distributed in the skin and sense a wide variety of pruritogens. *Nature Neuroscience*, *16*(2), 117–118. doi:10.1038/nn.3316

Nash, P., Wiley, K., Brown, J., Shinaman, R., Ludlow, D., Sawyer, A.-M., … Mackey, S. (2013). Functional magnetic resonance imaging identifies somatotopic organization of nociception in the human spinal cord. *Pain, 154*(6), 776–781. doi:10.1016/j.pain.2012.11.008

Näswall, K., Sverke, M., & Hellgren, J. (2005). The moderating role of personality characteristics on the relationship between job insecurity and strain. *Work & Stress, 19*(1), 37–49. doi:10.1080/02678370500057850

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. (2011). *Deep water: The Gulf Oil disaster and the future of offshore drilling: Report to the President*. Washington, DC: U.S. Government Printing Office.

Neal, A., & Griffin, M. A. (2004). Safety climate and safety at work. In J. Barling & M. R. Frone (Eds.), *The psychology of workplace safety* (pp. 15–34). Washington, DC: American Psychological Association.

Neal, A., & Griffin, M. A. (2006). A study of the lagged relationships among safety climate, safety motivation, safety behaviour, and accidents at the individual and group levels. *Journal of Applied Psychology, 91*(4), 946–953. doi:10.1037/0021-9010.91.4.946

Neal, A., Griffin, M. A., & Hart, P. M. (2000). The impact of organizational climate on safety climate and individual behaviour. *Safety Science, 34*(1–3), 99–109.

Neal, M. (2014). Preparing for extraterrestrial contact. *Risk Management: A Journal of Risk, Crisis and Disaster, 16*(2), 63–87. doi:10.1057/rm.2014.4

Neale V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J., & Goodman, M. (2005). *An Overview of the 100-car naturalistic study and findings* (Report 05-0400). Washington, DC: National Highway Traffic Safety Administration.

Neck, C. P., & Cooper, K. H. (2000). The fit executive: Exercise and diet guidelines for enhancing performance. *The Academy of Management Executive, 14*(2), 72–83. doi:10.5465/AME.2000.3819307

Neely, G. G., Rao, S., Costigan, M., Mair, N., Racz, I., Milinkeviciute, G., … Penninger, J. M. (2012). Construction of a global pain systems network highlights phospholipid signaling as a regulator of heat nociception. *PLoS Genetics, 8*(12), e1003071. doi:10.1371/journal.pgen.1003071

Neisser, F. M. (2014). 'Riskscapes' and risk management—Review and synthesis of an actor-network theory approach. *Risk Management: A Journal of Risk, Crisis and Disaster, 16*(2), 88–120. doi:10.1057/rm.2014.5

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology*. San Francisco, CA: Freeman.

Nembhard, I. M., & Edmondson, A. C. (2006). Making it safe: The effects of leader inclusiveness and professional status on psychological safety and improvement efforts in health care teams. *Journal of Organizational Behavior, 27*(7), 941–966. doi:10.1002/job.413.

Neuvel, J. M. M., de Boer, D. J., & Rodenhuis, W. K. F. (2015). Managing vulnerability: The implementation of vulnerability reduction measures. *Journal of Risk Research, 18*(2), 182–198. doi:10.1080/13669877.2014.889193

Newbold, E. M. (1926). *A contribution to the study of the human factor in the causation of accidents* (Report no. 34). London, UK: Industrial Health Research Board. (Reproduced in W. Haddon, E. A. Suchman, & D. Klein (Eds.) (1964), *Accident research: Methods and approaches.* New York, NY: Harper & Row.

Newby, K. V., French, D. P., Brown, K. E., & Wallace, L. M. (2013). Beliefs underlying chlamydia risk appraisals: The relationship with young adults' intentions to use condoms. *Journal of Risk Research, 16*(7), 843–860. doi:10.1080/13669877.2012.743158

Newcombe, T. M. (1943). *Personality and social change*. New York, NY: Dryden.

News Medical. (2000–2015). *Human Brain Structure*. http://www.newsmedical.net/health/Human-Brain-Structure.aspx. Accessed June 24, 2015.

Ng, T. W. H., Sorensen, K. L., & Eby, L. T. (2006). Locus of control at work: A meta-analysis. *Journal of Organizational Behavior, 27*(8), 1057–1087. doi:10.1002/job.416

Niedhammer, I., Chastang, J.-F., & David, S. (2008). Importance of psychosocial work factors on general health outcomes in the national French SUMER survey. *Occupational Medicine, 58*(1), 15–24. doi:10.1093/occmed/kqm115

Nielsen, M. B., Eid, J., Mearns, K., & Larsson, G. (2013). Authentic leadership and its relationship with risk perception and safety climate. *Leadership & Organization Development Journal, 34*(4), 308–325. doi:10.1108/LODJ-07-2011-0065

Nijhuis, F., Lendfers, M. L., de Jong, A., Janssen, P., & Ament, A. (1996). Stress–related interventions in construction work. In C. L. Cooper, P. Liukkonen, & S. Cartwright (Eds.), *Stress prevention in the workplace: Assessing the costs and benefits to organizations* (pp. 26–47). Dublin, Ireland: European Foundation for the Improvement of Living and Working Conditions.

Nixon, J., Campbell, J., Leggatt, A., Grindley, B., Smith, S., & Blackford, H. (2013). Using behavioural markers to support counter-IED training. *The Ergonomist, 514*, 12–13.

Noblet, A., & LaMontagne, A. D. (2006). The role of workplace health promotion in addressing job stress. *Health Promotion International, 21*(4), 346–353. doi:10.1097/JOM.0b013e31822005d0

Norris, F. H., Matthews, B. A., & Riad, J. K. (2000). Characterological, situational, and behavioral risk factors for motor vehicle accidents: A prospective examination. *Accident Analysis & Prevention, 32*(4), 505–515. doi:10.1016/S0001-4575(99)00068-8

Northoff, G., Heinzel, A., de Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain—A meta-analysis of imaging studies on the self. *Neuroimage, 31*(1), 440–457. doi:10.1016/j.neuroimage.2005.12.002

Northoff, G., Qin, P., & Feinberg, T. E. (2011). Brain imaging of the self–conceptual, anatomical and methodological issues. *Consciousness and Cognition, 20*(1), 52–63. doi:10.1016/j.concog.2010.09.011

Nudds, M. (2004). The significance of the senses. *Proceedings of the Aristotelian Society, 104*(1), 31–51. doi:10.1111/j.0066-7373.2004.00080.x

Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S. C. R., Parslow, D. M., Morgan, M. J., … Gray, J. A. (2002). Functional magnetic resonance imaging of synesthesia: Activation of V4/V8 by spoken words. *Nature Neuroscience, 5*(4), 371–375. doi:10.1038/nn818

Nyberg, A., Alfredsson, L., Theorell, T., Westerlund, H., Vahtera, J., & Kivimaki, M. (2009). Managerial leadership and ischaemic heart disease among employees: The Swedish WOLF study. *Occupational and Environmental Medicine, 66*(1), 51–55. doi:10.1136/oem.2008.039362

Öberg, T. (2014). Comment: Substitution of chemicals based on assessment of hazard, risk and impact. *Journal of Risk Research, 17*(5), 565–568. doi:10.1080/13669877.2013.841737

O'Boyle, E. H., Forsyth, D. R., Banks, G. C., & McDaniel, M. A. (2012). A meta-analysis of the dark triad and work behavior: A social exchange perspective. *Journal of Applied Psychology, 97*(3), 557–579. doi:10.1037/a0025679

O'Brien, L., Albert, D., Chein, J., & Steinberg, L. (2011). Adolescents prefer more immediate rewards when in the presence of their peers. *Journal of Research on Adolescence, 21*(4), 747–753. doi:10.1111/j.1532-7795.2011.00738.x

O'Brien, W. D. (2007). Ultrasound–biophysics mechanisms. *Progress in Biophysics and Molecular Biology, 93*(1–3), 212–255. doi:10.1016/j.pbiomolbio.2006.07.010

O'Connor, D. H., Fukui, M. M., Pinsk, M. A., & Kastner, S. (2002). Attention modulates responses in the human geniculate nucleus. *Nature Neuroscience, 5*(11), 1203–1209. doi:10.1038/nn957

Ode, S., Robinson, M. D., & Wilkowski, B. M. (2008). Can one's temper be cooled? A role for agreeableness in moderating neuroticism's influence on anger and aggression. *Journal of Research in Personality, 42*(2), 295–311. doi:10.1016/j.jrp.2007.05.007

O'Dea, A., & Flin, R. (2001). Site managers and safety leadership in the offshore and gas industry. *Safety Science, 37*(1), 39–57.

O'Doherty, J., Rolls, E. T., & Kringelbach, M. (2004). Neuroimaging studies of cross-modal integration for emotion. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 563–579). Cambridge, MA: MIT Press.

Ogunfowora, B. (2014). It's all a matter of consensus: Leader role modeling strength as a moderator of the links between ethical leadership and employee outcomes. *Human Relations, 67*(12), 1467–1490. doi:10.1177/0018726714521646

Øien, K. (2013). Remote operation in environmentally sensitive areas: Development of early warning indicators. *Journal of Risk Research, 16*(3–4), 323–336. doi:10.1080/13669877.2012.729523

Ojanen, K., Seppala, A., & Aaltonen, M. (1988). Measurement methodology for the effects of accident prevention programs. *Scandinavian Journal of Work, Environment and Health, 14*(1), 95–96.

Oliver, A., Cheyne, A., Tomás, J. M., & Cox, S. (2002). The effects of organizational and individual factors on occupational accidents. *Journal of Occupational and Organizational Psychology, 75*(4), 473–488. doi:10.1348/096317902321119691

Olofsson, A. (2014). Commentary: The substitution principle in chemical regulation: A constructive critique. *Journal of Risk Research*, *17*(5), 573–575. doi:10.1080/13669877.2013.841739

Olofsson, J. K. (2014). Time to smell: A cascade model of human olfactory perception based on response-time (RT) measurement. *Frontiers in Psychology*, *5*, 33. doi:10.3389/fpsyg.2014.00033

Olson, R., & Austin, J. (2001). Behavior–based safety and working alone: The effects of a self–monitoring package on the safe performance of bus operators. *Journal of Organizational Behavior Management*, *21*(3), 5–43. doi:10.1300/J075v21n03_02

Olsson, A., Ebert, J. P., Banaji, M. R., & Phelps, E. A. (2005). The role of social groups in the persistence of learned fear. *Science*, *309*(5735), 785–787. doi:10.1126/science.1113551

Ones, D. S., & Visweveran, C. (1996). *What do pre-employment customer service scales measure? Explorations in construct validity and implications for personnel selection*. Paper presented at the Annual Meeting of the Society for Industrial and Organizational Psychology, San Diego, CA.

Ones, D. S., Visweveran, C., & Schmidt, F. L. (1993). Comprehensive meta-analysis of integrity test validities: Findings and implications of personnel selection and theories of job performance. *Journal of Applied Psychology*, *78*(4), 679–703. doi:10.1037/0021-9010.78.4.679

O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, *24*(5), 939–973. doi:10.1017/S140525X01000115

Orencio, P. M., & Fujii, M. (2014). A spatiotemporal approach for determining disaster-risk potential based on damage consequences of multiple hazard events. *Journal of Risk Research*, *17*(7), 815–836. doi:10.1080/13669877.2013.816334

Organization for Human Brain Mapping. (2009). *Proceedings of the 15th Annual OHBM Meeting* (p. s41), June 18–23. San Francisco, CA.

Orio, P., Parra, A., Madrid, R., González, O., Belmonte, C., & Viana, F. (2012). Role of Ih in the firing pattern of mammalian cold thermoreceptor endings. *Journal of Neurophysiology*, *108*(11), 3009–3023. doi:10.1152/jn.01033.2011

Ormerod, T. C., & Dando, C. J. (2014). Finding a needle in a haystack: Toward a psychologically informed method for aviation security screening. *Journal of Experimental Psychology: General*, *144*(1), 76–84. doi:10.1037/xge0000030

Orr, C., & Hester, R. (2012). Error-related anterior cingulate cortex activity and the prediction of conscious error awareness. *Frontiers in Human Neuroscience*, *6*, 177. doi:10.3389/fnhum.2012.00177

Ostroff, L. E., Cain, C. K., Bedont, J., Monfils, M. H., & LeDoux, J. E. (2010). Fear and safety learning differentially affect synapse size and dendritic translation in the lateral amygdala. *Proceedings of the National Academy of Sciences*, *107*(20), 9418–9423. doi:10.1073/pnas.0913384107

O'Toole, M. F. (1999). Successful safety committees: Participation not legislation. *Journal of Safety Research*, *30*(1), 39–65.

O'Toole, M. F. (2002). The relationship between employees' perceptions of safety and organizational culture. *Journal of Safety Research*, *33*(2), 231–243.

Owen, A. M. (2013). Detecting consciousness: A unique role for neuroimaging. *Annual Review of Psychology*, *64*, 109–133. doi:10.1146/annurev-psych-113011-143729

Pablo, A. L. (1997). Reconciling predictions of decision making under risk. *Journal of Managerial Psychology*, *12*(1), 4–20. doi:10.1108/02683949710164217

Palmer, J. (2012). Risk governance in an age of wicked problems: Lessons from the European approach to indirect land-use change. *Journal of Risk Research*, *15*(5), 495–513. doi:10.1080/13669877.2011.643477

Paltrinieri, N., Dechy, N., Salzano, E., Wardman, M., & Cozzani, V. (2013). Towards a new approach for the identification of atypical accident scenarios. *Journal of Risk Research*, *16*(3–4), 337–354. doi:10.1080/13669877.2012.729518

Paltrinieri, N., Khan, F., & Cozzani, V. (2015). Coupling of advanced techniques for dynamic risk management. *Journal of Risk Research*, *18(7)*, 910–930. doi:10.1080/13669877.2014.919515

Pan, L.-j., Chortos, A., Yu, G-h., Wang, Y-q., Isaacson, S., Allen, R., … Bao, Z-n. (2014). An ultrasensitive resistive pressure sensor based on hollow-sphere microstructure induced elasticity in conducting polymer film. *Nature Communications*, *5*, 3002. doi:10.1038/ncomms4002

Paoli, P. (1997). *Second European Survey for the European Foundation for the Improvement of Living and Working Conditions*. Luxembourg.

Papadopoulos, T., Edwards, D. S., Rowan, D., & Allen, R. (2011). Identification of auditory cues utilized in human echolocation—Objective measurement results. *Biomedical Signal Processing and Control*, *6*(3), 280–290. doi:10.1016/j.bspc.2011.03.005

Parasuraman, R. (1998). *The attentive brain*. Cambridge, MA: MIT Press.

Parasuraman, R., & Galster, S. (2013). Sensing, assessing, and augmenting threat detection: Behavioral, neuroimaging, and brain stimulation evidence for the critical role of attention. *Frontiers in Human Neuroscience*, *7*, 273, 1–10. doi:10.3389/fnhum.2013.00273

Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing*, *30*(6), 653–661. doi:10.1523/JNEUROSCI.3256-09.2009

Park, W. (1990). A review of research on groupthink. *Journal of Behavioral Decision Making*, *3*(4), 229–245. doi:10.1002/bdm.3960030402

Parker, C. P., Baltes, B. B., Young, S. A., Huff, J. W., Altmann, R. A., LaCost, H. A., & Roberts, J. E. (2003). Relationships between psychological climate perceptions and work outcomes: A meta-analytic review. *Journal of Organizational Behavior*, *24*(4), 389–416. doi:10.1002/job.198

Parker, D., Manstead, A. S. R., & Stradling, S. G. (1995). Extending the theory of planned behavior: The role of personal norm. *British Journal of Social Psychology*, *34*(2), 127–137. doi:10.1111/j.2044-8309.1995.tb01053.x

Parker, D., Manstead, A. S. R., Stradling, S. G., & Reason, J. T. (1992). Determinants of intention to commit driving violations. *Accident Analysis and Prevention*, *24*(2), 117–131. doi:10.1016/0001-4575(92)90028-H

Parker, D., Manstead, A. S. R., Stradling, S. G., Reason, J. T., & Baxter, J. S. (1992). Intention to commit driving violations: An application of the theory of planned behavior. *Journal of Applied Psychology*, *77*(1), 94–101. doi:10.1037/0021-9010.77.1.94

Parker, D., McDonald, L., Rabbitt, P., & Sutcliffe, P. (2000). Elderly drivers and their accidents: The Aging Driver Questionnaire. *Accident Analysis & Prevention*, *32*(6), 751–759. doi:10.1016/S0001-4575(99)00125-6

Parker, D., Lajunen, T., & Stradling, S. G. (1998). Attitudinal predictors of interpersonally aggressive violations on the road. *Transportation Research Part F: Traffic Psychology and Behavior*, *1*(1), 11–24.

Parker, D., Lawrie, M., & Hudson, P., (2006). A framework for understanding the development of organizational safety culture. *Safety Science*, *44*, 551–562. doi:10.1016/j.ssci.2005.10.004.

Parker, D., West, R., Stradling, S. G., & Manstead, A. S. R. (1995). Behavioural characteristics and involvement in different types of traffic accident. *Accident Analysis & Prevention*, *27*(4), 571–581. doi:10.1016/0001-4575(95)00005-K

Parker, J. W. (1953). Psychological and personal history data related to accident records of commercial truck drivers. *Journal of Applied Psychology*, *37*(4), 317–320. doi:10.1037/h0053612

Parker, S. K. (2003). Longitudinal effects of lean production on employee outcomes and the mediating role of work characteristics. *Journal of Applied Psychology*, *88*(4), 620–634. doi:10.1037/0021-9010.88.4.620

Parker, S. K., Axtell, C. M., & Turner, N. (2001). Designing a safer workplace: Importance of job autonomy, communication quality and supportive supervisors. *Journal of Occupational Health Psychology*, *6*(3), 211–218. doi:10.1037/1076-8998.6.3.211

Parker, S. K., & Sprigg, C. A. (1999). Minimizing strain and maximizing learning: The role of job demands, job control, and proactive personality. *Journal of Applied Psychology*, *84*(6), 925–939. doi:10.1037/0021-9010.84.6.925

Parker, S. K., Turner, N., & Griffin, M. A. (2003). Designing healthy work. In D. A. Hofmann & L. E. Tetrick (Eds.), *Health and safety in organizations: A multilevel perspective* (pp. 91–130). San Francisco, CA: Jossey-Bass.

Parker, S. K., Williams, H. M., & Turner, N. (2006). Modeling the antecedents of proactive behavior at work. *Journal of Applied Psychology*, *91*(3), 636–652. doi:10.1037/0021-9010.91.3.636

Parkes, K. R. (1990). Coping, negative affectivity, and the work environment: Additive and interactive predictors of mental health. *Journal of Applied Psychology*, *75*(4), 399–409. doi:10.1037/0021-9010.75.4.399

Parry, K. W. (2002). Hierarchy of abstraction modeling (HAM) and the psychometric validation of grounded theory research. *International Journal of Organisational Behaviour*, *5*(5), 180–194.

Pascual-Leone, A., & Hamilton, R. (2001). The metamodal organization of the brain. *Progress in Brain Research*, *134*, 427–445. doi:10.1016/S0079-6123(01)34028-1
Paté-Cornell, E. (2012). On “Black Swans” and “Perfect Storms”: Risk analysis and management when statistics are not enough. *Risk Analysis*, *32*(11), 1823–1833. doi:10.1111/j.1539-6924.2011.01787.x
Patel, A. V., Bernstein, L., Deka, A., Feigelson, H. S., Campbell, P. T., Gapstur, S. M., … Thun, M. J. (2010). Leisure time spent sitting in relation to total mortality in a prospective cohort of US adults. *American Journal of Epidemiology*, *172*(4), 419–429. doi:10.1093/aje/kwq155
Patterson, E. S., Roth, E. M., Woods, D. D., Chow, R., & Gomes, J. O. (2004). Handoff strategies in settings with high consequences for failure: Lessons for health care operations. *International Journal for Quality in Health Care*, *16*(2), 125–132. doi:10.1093/intqhc/mzh026
Patterson, E. S., Woods, D. D., Cook, R. I., & Render, M. L. (2007). Collaborative cross-checking to enhance resilience. *Cognition, Technology & Work*, *9*(3), 155–162. doi:10.1007/s10111-006-0054-8
Pearce, C. L., & Sims, H. P. (2002). Vertical versus shared leadership as predictors of the effectiveness of change management teams: An examination of aversive, directive, transactional, transformational, and empowering leader behaviors. *Group Dynamics: Theory, Research, and Practice*, *6*(2), 172–197. doi:10.1177/001872675400700202
Pearson, C. A. L. (1992). Autonomous workgroups: An evaluation at an industrial site. *Human Relations*, *45*(9), 905–936. doi:10.1177/001872679204500903
Pedlar, M., Boydell, T., & Burgoyne, J. (1989). Towards the learning company. *Management Education and Development*, *20*(1), 1–8. doi:10.1177/135050768902000101
Pei, Y-C., Hsiao, S. S., Craig, J. C., & Bensmaia, S. J. (2010). Shape invariant coding of motion direction in somatosensory cortex. *PLoS Biology*, *8*(2), e1000305. doi:10.1371/journal.pbio.1000305
Peng, J., Miao, D., & Xiao, W. (2013). Why are gainers more risk seeking. *Judgment and Decision Making*, *8*(2), 150–160.
Penhune, V. B., Zatorre, R. J., & Feindel, W. H., (1999). The role of auditory cortex in retention of rhythmic patterns as studied in patients with temporal lobe removals including Heschl’s gyrus. *Neuropsychologia*, *37*(3), 315–331. doi:10.1016/S0028-3932(98)00075-X
Perko, T., Adam, B., & Stassen, K. R. (2015). The differences in perception of radiological risks: Lay people versus new and experienced employees in the nuclear sector. *Journal of Risk Research*, *18*(1), 40–54. doi:10.1080/13669877.2013.879488
Perko, T., Thijssen, P., Turcanu, C., & Van Gorp, B. (2014). Insights into the reception and acceptance of risk messages: Nuclear emergency communication. *Journal of Risk Research*, 17(9), 1207–1232. doi:10.1080/13669877.2013.875933
Perry, A. R. (1986). Type A behavior pattern and motor vehicle drivers’ behavior. *Perceptual and Motor Skills*, *63*(2), 875–878. doi:10.2466/pms.1986.63.2.875
Pertusa, M., Madrid, R., Morenilla-Palao, C., Belmonte, C., & Viana, F. (2012). *N*-glycosylation of TRPM8 ion channels modulates temperature sensitivity of cold thermoreceptor neurons. *The Journal of Biological Chemistry*, *287*(22), 18218–18229. doi:10.1074/jbc.M111.312645
Pervin, L. A., & John, O. P. (1999). *Handbook of personality: Theory and research* (2nd ed.). New York, NY: Guilford.
Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature Reviews Neuroscience*, *9*(2), 148–158. doi:10.1038/nrn2317
Peters, T. J., & Waterman, R. H. (1982). *In search of excellence*. New York, NY: Harper & Row.
Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89. doi:10.1146/annurev-neuro-062111-150525
Pettré, J., Siret, O., Marchal, M., de la Rivière, J.-B., & Lécuyer, A. (2011). *Joyman: An immersive and entertaining interface for virtual locomotion*. Proceedings of SIGGRAPH Asia 2011, Hong Kong, China, 12–15 December.
Phan, K. L., Fitzgerald, D. A., Nathan, P. J., & Tancer, M. E. (2006). Association between amygdala hyperactivity to harsh faces and severity of social anxiety in generalized social phobia. *Biological Psychiatry*, *59*(5), 424–429. doi:10.1016/j.biopsych.2005.08.012
Phelps, E. A. (2004). The human amygdala and awareness: Interactions between emotion and cognition. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1005–1015). Cambridge, MA: MIT Press.

Phillips, A. S., & Bedeian, A. G. (1994). Leader–follower exchange quality: The role of personal and interpersonal attributes. *The Academy of Management Journal*, *37*(4), 990–1001. doi:10.2307/256608

Picard, F., & Craig, A. D. (2009). Ecstatic epileptic seizures: A potential window on the neural basis for human self-awareness. *Epilepsy & Behavior*, *16*(3), 539–546. doi:10.1016/j.yebeh.2009.09.013

Picard, F., & Kurth, F. (2014). Ictal alterations of consciousness during ecstatic seizures. *Epilepsy & Behavior*, *30*(1), 58–61. doi:10.1016/j.yebeh.2013.09.036

Piccolo, R. F., Greenbaum, R., den Hartog, D. N., & Folger, R. (2010). The relationship between ethical leadership and core job characteristics. *Journal of Organizational Behavior*, *31*(2–3), 259–278. doi:10.1002/job.627

Pichon, S., de Gelder, B., & Grèzes, J. (2012). Threat prompts defensive brain responses independently of attentional control. *Cerebral Cortex*, *22*(2), 274–285. doi:10.1093/cercor/bhr060

Pidgeon, N. F. (1991). Safety culture and risk management in organizations. *Journal of Cross–Cultural Psychology*, *22*(1), 129–140. doi:10.1177/0022022191221009

Pidgeon, N. F. (1997). The limits to safety? Culture, politics, learning and man–made disasters. *Journal of Contingencies and Crisis Management*, *5*(1), 1–14. doi:10.1111/1468-5973.00032

Pidgeon, N. F. (1998). Safety culture: Key theoretical issues. *Work & Stress*, *12*(3), 202–216. doi:10.1080/02678379808256862

Pidgeon, N. F., & O'Leary, M. (2000). Man-made disasters: Why technology and organizations (sometimes) fail. *Safety Science*, *34*(1–3), 15–30.

Pillai, R., Schriesheim, C. A., & Williams, E. S. (1999). Fairness perceptions and trust as mediators for transformational and transactional leadership: A two-sample study. *Journal of Management*, *25*(6), 649–661. doi:10.1177/014920639902500606

Piqueras-Fiszman, B., & Spence, C. (2012). The weight of the container influences expected satiety, perceived density and subsequent expected fullness. *Appetite*, *58*(2), 559–562. doi:10.1016/j.appet.2011.12.021

Pizziol, S., Tessier, C., & Dehais, F. (2014). Petri net-based modelling of human–automation conflicts in aviation. *Ergonomics*, *57*(3), 319–331. doi:10.1080/00140139.2013.877597

Plack, C. (2012). Hearing pitch—Right place, wrong time? *The Psychologist*, *25*(12), 892–894.

Platt, M. J., & Huettel, S. A. (2008). Risky business: The neuroeconomics of decision making under uncertainty. *Nature Neuroscience*, *11*, 4. doi:10.1038/nn2062

Platte, J. E. (2014). Indian nuclear fuel cycle decision-making: An analysis of influences. *Journal of Risk Research*, *17*(1), 7–21. doi:10.1080/13669877.2013.822923

Plumert, J. M. (1995), Relations between children's overestimation of their physical abilities and accident proneness. *Developmental Psychology*, *31*(5), 866–876. doi:10.1037/0012-1649.31.5.866

Podsakoff, N. P., LePine, J. A., & LePine, M. A. (2007). Differential challenge stressor- hindrance stressor relationships with job attitudes, turnover intentions, turnover, and withdrawal behavior: A meta-analysis. *Journal of Applied Psychology*, *92*(2), 438–454. doi:10.1037/0021-9010.92.2.438

Podsakoff, P. M., MacKenzie, S. B., & Bommer, W. H. (1996). Meta analysis of the relationships between Kerr & Jermier's substitutes for leadership and employee attitudes, role perceptions, and performance. *Journal of Applied Psychology*, *81*(4), 380–399. doi:10.1037/0021-9010.81.4.380

Poelmans, S., Compernolle, T., De Neve, H., Buelens, M., & Rombouts, J. (1999). Belgium: A pharmaceutical company. In M. Kompier & C. L. Cooper (Eds.), *Preventing stress, improving productivity: European case studies in the workplace* (pp. 121–148). London, UK: Routledge.

Pohl, I. M., & Loke, L. (2012). Engaging the sense of touch in interactive architecture. *Proceedings of the 24th Australian Computer-Human Interaction Conference* (*OZCHI'12*, pp. 493–496). (26–30 November). Melbourne, Victoria, Australia.

Pollatos, O., Kirsch, W., & Schandry, R. (2005). On the relationship between interoceptive awareness, emotional experience, and brain processes. *Cognitive Brain Research*, *25*(3), 948–962. doi:10.1016/j.cogbrainres.2005.09.019

Pollock, R. A., Carter, A. S., Amir, N., & Marks, L. E. (2006). Anxiety sensitivity and auditory perception of heartbeat. *Behaviour Research and Therapy*, *44*(12), 1739–1756. doi:10.1016/j.brat.2005.12.013

Porges, S. W. (1998). Love: An emergent property of the mammalian autonomic nervous system. *Psychoneuroendocrinology*, *23*(8), 837–861. doi:10.1016/S0306-4530(98)00057-2

Porter, C. S. (1988). Accident proneness: A review of the concept. In D. J. Oborne (Ed.), *International reviews of ergonomics: Current trends in human factors research and practice* (Vol. 2, pp. 177–206). London, UK: Taylor & Francis.

Porter, C. S., & Corlett. E. N. (1989). Performance differences of individuals classified by questionnaire as accident prone or non-accident prone. *Ergonomics*, *32*(3), 317–333. doi:10.1080/00140138908966091

Portnoy, D. B., Kaufman, A. R., Klein, W. M. P., Doyle, T. A., & de Groot, M. (2014). Cognitive and affective perceptions of vulnerability as predictors of exercise intentions among people with type 2 diabetes. *Journal of Risk Research*, *17*(2), 177–193. doi:10.1080/13669877.2013.794153

Posner, M. I., & Boies, S. (1971), Components of attention. *Psychological Review*, *78*(5), 391–408.

Posner, M. I., & DiGirolamo, G. J. (2000). Attention in cognitive neuroscience: An overview. In Gazzaniga, M. S. (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 623–631). Cambridge, MA: MIT Press.

Posner, M. I., & Rothbart, M. K. (2009). Toward a physical basis of attention and self-regulation. *Physics of Life Reviews*, *6*(2), 103–120. doi:10.1016/j.plrev.2009.02.001

Powers, P. A., Andriks, J. L., & Loftus, E, F. (1979). Eyewitness accounts of females and males. *Journal of Applied Psychology*, *64*(3), 339–347. doi:10.1037/0021-9010.64.3.339

Powley, T. L., & Phillips, R. J. (2004). Gastric satiation is volumetric, intestinal satiation is nutritive. *Physiology and Behavior*, *82*(1), 69–74. doi:10.1016/j.physbeh.2004.04.037

Prasanna, R., Yang, L., & King, M. (2013). Guidance for developing human-computer interfaces for supporting fire emergency response. *Risk Management: A Journal of Risk, Crisis and Disaster, 15*(3), 155–179. doi:10.1057/rm.2013.3

Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., … Pause, B. M. (2009). Induction of empathy by the smell of anxiety. *PLoS One*, *4*(6), e5987. doi:10.1371/journal.pone.0005987

Preuschoff, K., Quartz, S. R., & Bossaerts, P. (2008). Human insula activation reflects risk prediction errors as well as risk. *The Journal of Neuroscience*, *28*(11), 2745–2752. doi:10.1523/JNEUROSCI.4286-07.2008

Prezelj, I., & Žiberna, A. (2013). Consequence-, time- and interdependency-based risk assessment in the field of critical infrastructure. *Risk Management: A Journal of Risk, Crisis and Disaster, 15*(2), 100–131. doi:10.1057/rm.2013.1

Prior, T., & Hagmann, J. (2014). Measuring resilience: Methodological and political challenges of a trend security concept. *Journal of Risk Research*, *17*(3), 281–298. doi:10.1080/13669877.2013.808686

Probst, T. M. (2004a). Job insecurity: Exploring a new threat to employee safety. In J. Barling & M. R. Frone (Eds.), *The psychology of workplace safety* (pp. 63–80). Washington, DC: American Psychological Association.

Probst, T. M. (2004b). Safety and insecurity: Exploring the moderating effect of organizational safety climate. *Journal of Occupational Health Psychology*, *9*(1), 3–10. doi:10.1037/1076-8998.9.1.3

Probst, T. M., & Brubaker, T. L. (2001). The effects of job insecurity on employee safety outcomes: Cross–sectional and longitudinal explorations. *Journal of Occupational Health Psychology, 6*(2), 139–159. doi:10.1037/1076-8998.6.2.139

Proulx, M. J. (2010). Synthetic synaesthesia and sensory substitution. *Consciousness and Cognition*, *19*(1), 501–503. doi:10.1016/j.concog.2009.12.005

Prussia, G. E., Brown, K. A., & Willis, P. G. (2003). Mental models of safety: Do managers and employees see eye to eye? *Journal of Safety Research*, *34*(2), 143–156. doi:10.1016/S0022-4375(03)00011-2

Pryce, G., & Chen, Y. (2011). Flood risk and the consequences for housing of a changing climate: An international perspective. *Risk Management: An International Journal*, *13*(4), 228–246. doi:10.1057/rm.2011.13

Qi, X-x., Vitousek, P. M., & Liu, L-m. (2015). Identification and evaluation of risk factors related to provincial food insecurity in China. *Journal of Risk Research*, doi:10.1080/13669877.2014.913667

Quick, J., & Quick, J. (1984). *Organizational stress and preventative management*. New York, NY: McGraw–Hill.

Raaschou-Nielsen, O., Andersen, Z. J., Beelen, R., Samoli, E., Stafoggia, M., Weinmayr, G., … Hoek, G. (2013). Air pollution and lung cancer incidence in 17 European cohorts: Prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). *The Lancet Oncology*, *14*(9), 813–822. doi:10.1016/S1470-2045(13)70279-1

Rafferty, A. E., & Griffin, M. A. (2004). Dimensions of transformational leadership: Conceptual and empirical extensions. *The Leadership Quarterly*, *15*(3), 329–354. doi:10.1016/j.leaqua.2004.02.009

Raihani, N. J. (2013). Nudge politics: Efficacy and ethics. *Frontiers in Psychology*, *4*, 972. doi:10.3389/fpsyg.2013.00972

Raij, T., & Jousmäki, V. (2004). MEG studies of cross-modal integration and plasticity. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 515–528). Cambridge, MA: MIT Press.

Ramana, M. V., & Kumar, A. (2014). 'One in infinity': Failing to learn from accidents and implications for nuclear safety in India. *Journal of Risk Research*, *17*(1), 23–42. doi:10.1080/13669877.2013.822920

Rand, M. K., Wang, L., Müsseler J., & Heuer, H. (2013). Vision and proprioception in action monitoring by young and older adults. *Neurobiology of Aging*, *34*(7), 1864–1872. doi:10.1016/j.neurobiolaging.2013.01

Ranyard, R., & McHugh, S. (2012). Bounded rationality in credit consumers' payment protection insurance decisions: The effect of relative cost and level of cover. *Journal of Risk Research*, *15*(8), 937–950. doi:10.1080/13669877.2012.686050

Räsänen, P., Näsi, M., & Sarpila, O. (2012). Old and new sources of risk: A study of societal risk perception in Finland. *Journal of Risk Research*, *15*(7), 755–769. doi:10.1080/13669877.2012.657218

Rasmussen, J. (1983). Skills, rules, knowledge: Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics*, *13*, 257–266.

Rast, P., Zimprich, D., Van Boxtel, M., & Jolles, J. (2009). Factor structure and measurement invariance of the cognitive failures questionnaire across the adult life span. *Assessment*, *16*(2), 145–158. doi:10.1177/1073191108324440

Rathert, C., Williams, E. S., Lawrence, E. R., & Halbesleben, J. R. (2012). Emotional exhaustion and workarounds in acute care: Cross sectional tests of a theoretical framework. *International Journal of Nursing Studies*, *49*(8), 969–977. doi:10.1016/j.ijnurstu.2012.02.011

Rawls, J. (2001). *Justice as fairness: A restatement*. Cambridge, MA: Belknap.

Raymark, P. H., Schmit, M. J., & Guion, R. M. (1997). Identifying potentially useful personality constructs for employees' selection. *Personnel Psychology*, *50*(3), 723–736. doi:10.1111/j.1744-6570.1997.tb00712.x

Reader, T. W., & O'Connor, P. (2014). The Deepwater Horizon explosion: Non-technical skills, safety culture, and system complexity. *Journal of Risk Research*, *17*(3), 405–424. doi:10.1080/13669877.2013.815652

Reason, J. (1988, June). Errors and violations: The lessons of Chernobyl. In *Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants* (pp. 537–540). Monterey, CA: Institute of Electrical and Electronics Engineers. doi:10.1109/HFPP.1988.27561

Reason, J. T. (1974, 21 February). Style, personality and accidents. *New Society*.

Reason, J. T. (1976, 4 November). Absent minds. *New Society*, 4 November, 244–245.

Reason, J. T. (1987). The Chernobyl errors. *Bulletin of the British Psychological Society*, *40*, 201–206.

Reason, J. T. (1988). Stress and cognitive failure. In S. Fisher & J. T. Reason (Eds.), *Handbook of life stress, cognition and health* (pp. 405–421). Chichester, UK: Wiley.

Reason, J. T. (1990). *Human error*. Cambridge, UK: Cambridge University Press.

Reason, J. T. (1993). Managing the management risk: New approaches to organizational safety. In B. Wilpert & T. Qvale (Eds.), *Reliability and safety in hazardous work systems* (pp. 7–22). Hove, UK: Erlbaum.

Reason, J. T. (1995). A systems approach to organizational error. *Ergonomics*, *38*(8), 1708–1721. doi:10.1080/00140139508925221

Reason, J. T. (1997). *Managing the risks of organizational accidents*. Aldershot, UK: Ashgate.

Reason, J. T. (1998). Achieving a safe culture: Theory and practice. *Work & Stress*, *12*(3), 293–306. doi:10.1080/02678379808256868

Reason, J. T. (2000). Human error: Models and management. *British Medical Journal*, 320, 768–770. doi:10.1136/bmj.320.7237.768
Reason, J. T., & Lucas, D. (1984). Using cognitive diaries to investigate naturally occurring memory blocks. In J. E. Harris & P. E. Morris (Eds.), *Everyday memory actions and absent–mindedness* (pp. 53–70). London, UK: Academic Press.
Reason, J. T., Manstead, A. S. R., Stradling, S. G., Baxter, J. S., & Campbell, K. (1990). Errors and violations on the road: A real distinction? *Ergonomics*, *33*(10–11), 1315–1332. doi:10.1080/00140139008925335
Reason, J. T., & Mycielska, K. (1982) *Absent-minded? The psychology of mental lapses and everyday errors.* Englewood Cliffs, NJ: Prentice Hall.
Reason, J. T., Parker, D., & Free, R. (1994). *Bending the rules: The varieties, origins and management of safety violations.* Leiden, the Netherlands: Rijks Universiteit Leiden.
Reason, J. T., Parker, D., & Lawton, R. (1998). Organizational controls and safety: The varieties of rule–related behaviour. *Journal of Occupational and Organizational Psychology*, *71*(4), 289–304. doi:10.1111/j.2044-8325.1998.tb00678.x
Recanzone, G. H. (2004). Acoustic stimulus processing and multimodal interactions in primates. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 359–367). Cambridge, MA: MIT Press.
Rees, G. (2004). Neural correlates of visual consciousness in humans. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1173–1188). Cambridge, MA: MIT Press.
Regan, Á., Raats, M., Shan, L. C., Wall, P. G., & McConnon, Á. (2015). Risk communication and social media during food safety crises: A study of stakeholders' opinions in Ireland. *Journal of Risk Research*. doi:10.1080/13669877.2014.961517
Renn, O. (2014). Comment on paper: The substitution principle by Ragnar Löfstedt. *Journal of Risk Research*, *17*(5), 597–599. doi:10.1080/13669877.2014.880729
Renn, O., & Benighaus, C. (2013). Perception of technological risk: Insights from research and lessons for risk communication and management. *Journal of Risk Research*, *16*(3–4), 293–313. doi:10.1080/13669877.2012.729522
Renn, O., Grieger, K. D., Øien, K., & Andersen, H. B. (2013). Benefit-risk trade-offs in retrospect: How major stakeholders perceive the decision-making process in the Barents Sea oil field development. *Journal of Risk Research*, *16*(9), 1163–1185. doi:10.1080/13669877.2012.761266
Resick, C. J., Whitman, D. S., Weingarden, S. M., & Hiller, N. J. (2009). The bright-side and the dark-side of CEO personality: Examining core self-evaluations, narcissism, transformational leadership, and strategic influence. *Journal of Applied Psychology*, *94*(6), 1365–1381. doi:10.1037/a0016238
Revollo-Fernandez, D. A., & Aguilar-Ibarra, A. (2014). Measures of risk associated to regulations compliance: A laboratory experiment on the use of common-pool resources. *Journal of Risk Research*, *17*(7), 903–921. doi:10.1080/13669877.2013.822914
Reyna, V. F., Chick, C. F., Corbin, J. C., & Hsia, A. N. (2013). Developmental reversals in risky decision making: Intelligence agents show larger decision biases than college students. *Psychological Science*, *25*(1), 76–84. doi:10.1177/0956797613497022
Reyna, V. F., & Heutel, S. A. (2014). Reward, representation, and impulsivity: A theoretical framework for the neuroscience of risky decision making. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 11–42). Washington, DC: American Psychological Association. doi:10.1037/14322-002
Reyners, P. (2014). Underground nuclear repositories and international civil liability: The time factor. *Journal of Risk Research*, *17*(1), 133–143. doi:10.1080/13669877.2013.841740
Ricciardi, E., Basso, D., Sani, L., Bonino, D., Vecchi, T., Pietrini, P., & Miniussi, C. (2011). Functional inhibition of the human middle temporal cortex affects non-visual motion perception: A repetitive transcranial magnetic stimulation study during tactile speed discrimination. *Experimental Biology and Medicine*, *236*(2), 138–144. doi:10.1258/ebm.2010.010230
Richardson, K. M., & Rothstein, H. R. (2008). Effects of occupational stress management intervention programs: A meta-analysis. *Journal of Occupational Health Psychology*, *13*(1), 69–93. doi:10.1037/1076-8998.13.1.69
Richardson, P. L. (2015). Upwind dynamic soaring of albatrosses and UAVs. *Progress in Oceanography*, *130*, 146–156. doi:10.1016/j.pocean.2014.11.002

Richter, A. (2003). New ways of managing prevention: A cultural and participative approach. *Safety Science Monitor, 7*(1), II–2.

Richter, A., & Koch, C. (2004). Integration, differentiation and ambiguity in safety cultures. *Safety Science, 42*(8), 703–722. doi:10.1016/j.ssci.2003.12.003

Rickard, L. N., McComas, K. A., Clarke, C. E., Stedman, R. C., & Decker, D. J. (2013). Exploring risk attenuation and crisis communication after a plague death in Grand Canyon. *Journal of Risk Research, 16*(2), 145–167. doi:10.1080/13669877.2012.725673

Riekki, T., Lindeman, M., Aleneff, M., Halme, A., & Nuortimo, A. (2012). Paranormal and religious believers are more prone to illusory face perception than skeptics and non-believers. *Applied Cognitive Psychology, 27*(2), 150–155. doi:10.1002/acp.2874

Rifkin, J. (2014). *The zero marginal cost society: The internet of things, the collaborative commons, and the eclipse of capitalism.* Basingstoke, UK: Palgrave Macmillan.

Ritter, A., Franz, M., Dietrich, C., Miltner, W. H. R., & Weiss, T. (2013). Human brain stem structures respond differentially to noxious heat. *Frontiers in Human Neuroscience, 7*, 530. doi:10.3389/fnhum.2013.00530

Rivelin, R., & Gravelle, K. (1984). *Deciphering the senses: The expanding world of human perception*. New York, NY: Simon & Schuster.

Robbins, S. P., Millett, B., Cacioppe, R., & Waters-Marsh, T. (2001). *Organizational behavior: Leading and managing in Australia and New Zealand* (3rd ed.). Frenchs Forest, New South Wales, Australia: Pearson Education Australia.

Roberson, D. P., Gudes, S., Sprague, J. M., Patoski, H. A. W., Robson, V. K., Blasl, F., … Woolf, C. J. (2013). Activity-dependent silencing reveals functionally distinct itch-generating sensory neurons *Nature Neuroscience, 16*(7), 910–918. doi:10.1038/nn.3404

Roberts, D. S. & Geller, E. S. (1995). An "actively caring" model for occupational safety: A field test. *Applied and Preventive Psychology, 4*(1), 53–59.

Roberts, K. H. (1989). New challenges in organizational research: High reliability organizations. *Organization & Environment, 3*(2), 111–125. doi:10.1177/108602668900300202

Roberts, K. H. (1993). Cultural characteristics of reliability enhancing organizations. *Journal of Managerial Issues, 5*(2), 165–181.

Robertson, I. H., & Garavan, H. (2004). Vigilant attention. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 631–640). Cambridge, MA: MIT Press.

Robertson, I. T., Baron, H., Gibbons, P., MacIver, R., & Nyfield, G. (2000). Conscientiousness and managerial performance. *Journal of Occupational and Organizational Psychology, 73*(2), 171–180. doi:10.1348/096317900166967

Robertson, I. T., & Kinder, A. (1993). Personality and job competences: The criterion-related validity of some personality variables. *Journal of Occupational and Organizational Psychology, 66*(3), 225–244. doi:10.1111/j.2044-8325.1993.tb00534.x

Robertson, I. T., & Smith, M. (2001). Personnel selection. *Journal of Occupational and Organizational Psychology, 74*(4), 441–473. doi:10.1348/096317901167479

Robinson, R. (2010). Touch neurons have a good sense of direction. *PLoS Biology, 8*(2), e1000304. doi:10.1371/journal.pbio.1000304

Robinson, S. E. (1996). Trust and breach of the psychological contract. *Administrative Science Quarterly, 41*(4), 574–599.

Rochlin, G. I. (1989). Informal organizational networking as a crisis-avoidance strategy: US naval flight operations as a case study. *Organization Environment, 3*(2), 159–176. doi:10.1177/108602668900300205

Rød, J. K., Opach, T., & Neset, T-S. (2015). Three core activities toward a relevant integrated vulnerability assessment: Validate, visualize, and negotiate. *Journal of Risk Research, 18(7)*, 877–895. doi:10.1080/13669877.2014.923027

Rød, S. K., Botan, C., & Holen, A. (2012). Risk communication and worried publics in an imminent rockslide and tsunami situation. *Journal of Risk Research, 15*(6), 645–654. doi:10.1080/13669877.2011.652650

Rodrigo, M. J., Padrón, I., de Vega, M., & Ferstl, E. C. (2014). Adolescents' risky decision-making activates neural networks related to social cognition and cognitive control processes. *Frontiers in Human Neuroscience, 8*, 60. doi:10.3389/fnhum.2014.00060

Rodríguez, H. (2015). From objective to constituted risk: An alternative approach to safety in strategic technological innovation in the European Union. *Journal of Risk Research*. doi:10.1080/13669877.2014.940596

Rodriguez, M. A., & Griffin, M. A. (2009). From error prevention to error learning: The role of error management in global leadership. *Advances in Global Leadership*, *5*, 93–112. doi:10.1108/S1535-1203(2009)0000005008

Roelofs, K., Hagenaars, M. A., & Stins, J. (2010). Facing freeze: Social threat induces bodily freeze in humans. *Psychological Science*, *21*(11), 1575–1581. doi:10.1177/0956797610384746

Roesler, M. L., Glendon, A. I., & O'Callaghan, F. V. (2013). Recovering from traumatic occupational hand injury following surgery: A biopsychosocial perspective. *Journal of Occupational Rehabilitation*, *23*(4), 536–546. doi:10.1007/s10926-013-9422-4

Roethlisberger, F. J., & Dickson, W. J. (1939). *Management and the worker*. Cambridge, MA: Harvard University Press.

Rolls, E. T. (2004). Multisensory neuronal convergence of taste, somatosensory, visual, olfactory, and auditory inputs. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 311–331). Cambridge, MA: MIT Press.

Römer, K., & Mattern, F. (2004, December). The design space of wireless sensor networks. *IEEE Wireless Communications*, *12*, 54–61.

Roodenrijs, J. C. M., Kraaij-Dirkzwager, M. M., van den Kerkhof, J. H. T. C., & Runhaar, H. A. C. (2014). Risk governance for infectious diseases: Exploring the feasibility and added value of the IRGC-framework for Dutch infectious disease control. *Journal of Risk Research*, *17*(9), 1161–1182. doi:10.1080/13669877.2013.875935

Roosli, R., & O'Keefe, P. (2011). An evaluation of barriers in implementing disaster planning and the housing programme in Malaysia. *Risk Management: An International Journal*, *13*(4), 209–227. doi:10.1057/rm.2011.16

Rosa, R. R. (1995). Extended work shifts and excessive fatigue. *Journal of Sleep Research*, *4*(S2), 51–56. doi:10.1111/j.1365-2869.1995.tb00227.x

Rosa, R. R., Colligan, M. J., & Lewis, P. (1989). Extended work days: Effects of 8-hour and 12-hour rotating schedules on performance, subjective, alertness, sleep patterns and psychosocial variables. *Work & Stress*, *3*(1), 21–32. doi:10.1080/02678378908256877

Rosario del Grayham, D. A. (January, 1984). Behavioural science–Small work group. *The Safety Practitioner*, 17–22.

Rosen, L. D., Carrier, L., & Cheever, N. A. (2013). Facebook and texting made me do it: Media-induced task-switching while studying. *Computers in Human Behavior*, *29*(3), 948–958. doi:10.1016/j.chb.2012.12.001

Rosenblum, L. D., & Gordon, M. S. (2012). The exotic sensory capabilities of humans. *The Psychologist*, *25*(12), 904–907.

Rossignol, N., Turcanu, C., Fallon, C., & Zwetkoff, C. (2015). "How are you vulnerable?" Using participation for vulnerability analysis in emergency planning. *Journal of Risk Research*. doi:10.1080/13669877.2014.961522

Rothstein, H. (2013). Domesticating participation: Participation and the institutional rationalities of science-based policy-making in the UK food standards agency. *Journal of Risk Research*, *16*(6), 771–790. doi:10.1080/13669877.2013.775180

Rousseau, D. M. (1988). The construction of climate in organizational research. In C. L. Cooper & I. T. Robertson (Eds.), *International review of industrial and organizational psychology* (Vol. 3, pp. 139–158). Chichester, England: Wiley.

Rousseau, D. M. (1990). Assessing organizational culture: The case for multiple methods. In B. Schneider (Ed.), *Organizational climate and culture* (pp. 153–192). San Francisco, CA: Jossey-Bass.

Rowold, J. (2011). Relationship between leadership behaviors and performance: The moderating role of a work team's level of age, gender, and cultural heterogeneity. *Leadership & Organization Development Journal*, *32*(6), 628–647. doi:10.1108/01437731111161094

Roy, G. S., & Choudhary, R. K. (1985). Driver control as a factor in road safety. *Asian Journal of Psychology & Education*, *16*(3), 33–37.

Roy, M. (2003). Self–directed work teams and safety: A winning combination? *Safety Science*, *41*(4), 359–376.

Royal Society of Chemistry (2014). Comment: The substitution principle in chemical regulation: A constructive critique (Löfstedt, R.). *Journal of Risk Research*, *17*(5), 577–580. doi:10.1080/13669877.2013.841741

Rudenga, K., Green, B., Nachtigal, D., & Small, D. M. (2010). Evidence for an integrated oral sensory module in the human anterior ventral insula. *Chemical Senses*, *35*(8), 693–703. doi:10.1093/chemse/bjq068

Rudisill, C. (2013). How do we handle new health risks? Risk perception, optimism, and behaviors regarding the H1N1 virus. *Journal of Risk Research*, *16*(8), 959–980. doi:10.1080/13669877.2012.761271

Rudwill, F., Blanc, S., Gauquelin-Koch, G., Chouker, A., Heer, M., Simon, C., & Bergouignan, A. (2013). Effects of different levels of physical inactivity on plasma visfatin in healthy normal-weight men. *Applied Physiology, Nutrition, and Metabolism*, *38*(6), 689–693. doi:10.1139/apnm-2012-0434

Ruiz, M. H., Strübing, F., Jabusch, H. C., & Altenmüller, E. (2011). EEG oscillatory patterns are associated with error prediction during music performance and are altered in musician's dystonia. *NeuroImage*, *55*(4), 1791–1803. doi:10.1016/j.neuroimage.2010.12.050

Rundmo, T. (2000). Safety climate, attitudes and risk perception in Norsk Hydro. *Safety Science*, *34*(1–3), 47–59.

Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognisers: People with extraordinary face recognition ability. *Psychonomic Bulletin & Review*, *16*(2), 252–257. doi:10.3758/PBR.16.2.252

Ryan, T. G. (1991, July). *Organisational Factors Regulatory Research Briefing to the ACSNI Study Group on Human Factors and Safety*. London, UK: Advisory Committee on the Safety of Nuclear Installations.

Ryu, Y., & Kim, S. (2015). Testing the heuristic/systematic information-processing model (HSM) on the perception of risk after the Fukushima nuclear accidents. *Journal of Risk Research*, *18(7)*, 840–859. doi:10.1080/13669877.2014.910694

Sah, A. P. (1989). Personality characteristics of accident free and accident involved Indian railway drivers. *Journal of Personality and Clinical Studies*, *5*(2), 203–206.

Sahlin, N-E., & Hermerén, G. (2012). Personalised, predictive and preventive medicine: A decision theoretic perspective. *Journal of Risk Research*, *15*(5), 453–457. doi:10.1080/13669877.2011.634524

Saiita, P. (2012). History, space, and power: Theoretical and methodological problems in the research on areas at (industrial) risk. *Journal of Risk Research*, *15*(10), 1299–1317. doi:10.1080/13669877.2012.571785

Salas, E., Cooke, N. J., & Rosen, M. A. (2008). On teams, teamwork, and team performance: Discoveries and developments. *Human Factors*, *50*(3), 540–547. doi:10.1518/001872008X288457

Salas, E., Fowlkes, J. E., Stout, R. J., Milanovich, D. M., & Prince, C. (1999). Does CRM training improve teamwork skills in the cockpit? Two evaluation studies. *Human Factors*, *41*(2), 326–343. doi:10.1518/001872099779591169

Salgado, J. F. (1997). The five factor model of personality and job performance in the European Community. *Journal of Applied Psychology*, *82*(1), 30–43. doi:10.1037/0021-9010.82.1.30

Salgado, J. F. (1998). Big five personality dimensions and job performance in army and civil occupations: A European perspective. *Human Performance*, *11*(2–3), 271–288. doi:10.1080/08959285.1998.9668034

Salgado, J. F. (2002). The Big Five personality dimensions and counterproductive behaviors. *International Journal of Selection and Assessment*, *10*(1–2), 117–125. doi:10.1111/1468-2389.00198

Salminen, S., & Klen, T. (1994). Accident locus of control and risk taking among forestry and construction workers. *Perceptual and motor skills*, *78*(3), 852–854. doi:10.2466/pms.1994.78.3.852

Salmon, P. M., Lenné, M. G., Walker, G. H., & Filtness, A. (2013). Investigating the factors influencing cyclist awareness and behaviour: An on-road study of cyclist situation awareness. *Journal of the Australasian College of Road Safety*, *24*(4), 7–14.

Salmon, P. M., Lenné, M. G., Young, K. L., & Walker, G. H. (2013). An on-road network analysis-based approach to studying driver situation awareness at rail level crossings. *Accident Analysis and Prevention*, *58*, 195–205. doi:10.1016/j.aap.2012.09.012

Salmon, P. M., Read, G. J., Stanton, N. A., & Lenné, M. G. (2013). The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. *Accident Analysis and Prevention*, *50*, 1278–1288. doi:10.1016/j.aap.2012.09.029

Salmon, P. M., & Stanton, N. A. (2013). Situation awareness and safety: Contribution or confusion? Situation awareness and safety editorial. *Safety Science*, *56*, 1–5. doi:10.1016/j.ssci.2012.10.011

Salmon, P. M., Stanton, N. A., Walker, G. H., & Jenkins, D. P. (2009). *Distributed situation awareness: Advances in theory, measurement and application to teamwork*. Aldershot, UK: Ashgate.

Salmon, P. M., Walker G. H., & Stanton, N. A. (2015). Broken components versus broken systems: Why it is systems not people that lose situation awareness. *Cognition, Technology & Work*, *17*, 179–183. doi:10.1007/s10111-015-0324-4

Salmon, P. M., Young, K. L., & Cornelissen, M. (2013). Compatible cognition amongst road users: The compatibility of driver, motorcyclist, and cyclist situation awareness. *Safety Science*, *56*, 6–17. doi:10.1016/j.ssci.2012.02.008

Salzano, E., Basco, A., Busini, V., Cozzani, V., Marzo, E., Rota, R., & Spadoni, G. (2013). Public awareness promoting new or emerging risks: Industrial accidents triggered by natural hazards (NaTech). *Journal of Risk Research*, *16*(3–4), 469–485. doi:10.1080/13669877.2012.729529

Samanez-Larkin, G. R., & Knutson, B. (2014). Reward processing and risky decision making in the aging brain. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 123–142). Washington, DC: American Psychological Association. doi:10.1037/14322-006

Sampson, J. M., DeArmond, S., & Chen, P. Y. (2014). Role of safety stressors and social support on safety performance. *Safety Science*, *64*, 137–145. doi:10.1016/j.ssci.2013.11.025

Samsonov, A., & Popov, S. V. (2013). The effect of a 94 GHz electromagnetic field on neuronal microtubules. *Bioelectromagnetics*, *34*(2), 133–144. doi:10.1002/bem.21760

Sathian, K., Prather, S. C., & Zhang, M. (2004). Visual cortical involvement in normal tactile perception. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 703–709). Cambridge, MA: MIT Press.

Saunders, R. D., & Jefferys, J. G. (2002). Weak electric field interactions in the central nervous system. *Health Physics*, *83*(3), 366–375.

Saville and Holdsworth Ltd. (1984). *Occupational Personality Questionnaires manual.* Esher, UK: Saville and Holdsworth.

Saville and Holdsworth Ltd. (1985). *OPQ update number 1.* Esher, UK: Saville and Holdsworth.

Sawalha, I. H. S., Anchor, J. R., & Meaton, J. (2012). Business continuity management in Jordanian banks: Some cultural considerations *Risk Management: A Journal of Risk, Crisis and Disaster*, *14*(4), 301–324. doi:10.1057/rm.2012.10

Say, M. J., Jones, R., Scahill, R. I., Dumas, E. M., Coleman, A., Dar Santos, R. C., … Stout, J. C. (2011). Visuomotor integration deficits precede clinical onset in Huntington's disease. *Neuropsychologia*, *49*(2), 264–270. doi:10.1016/j.neuropsychologia.2010.11.016

Schafe, G. E., & LeDoux, J. E. (2004). The neural basis of fear. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 987–1003). Cambridge, MA: MIT Press.

Schaller, M., & Neuberg, S. L. (2012). Danger, disease, and the nature of prejudice(s). In J. M. Olson & M. P. Zanna (Eds.), *Advances in experimental social psychology*, (Vol. 46, pp. 1–54). Burlington, VT: Academic Press. doi:10.1016/B978-0-12-394281-4.00001-5

Schaller, M., Park, J. H., & Kenrick, D. T. (2007). Human evolution and social cognition. In R. I. M. Dunbar & L. Barrett (Eds.), *Oxford handbook of evolutionary psychology* (pp. 491–504). Oxford, UK: Oxford University Press.

Schaubroeck, J., & Fink, L. (1998). Facilitating and inhibiting effects of job control and social support on stress outcomes and role behavior: A contingency model. *Journal of Organizational Behavior*, *19*(2), 167–195.

Schaubroeck, J., & Merritt, D. E. (1997). Divergent effects of job control on coping with work stressors: The key role of self-efficacy. *Academy of Management Journal*, *40*(3), 738–754. doi: 10.2307/257061

Schaufeli, W. B., Bakker, A. B., & Van Rhenen, W. (2009). How changes in job demands and resources predict burnout, work engagement, and sickness absenteeism. *Journal of Organizational Behavior*, *30*(7), 893–917. doi:10.1002/job.595

Scheer, D. (2013). Risk governance and emerging technologies: Learning from case study integration. *Journal of Risk Research*, *16*(3–4), 355–368. doi:10.1080/13669877.2012.729519

Schein, E. H. (1985). *Organizational culture and leadership*. San Francisco, CA: Jossey–Bass.

Schein, E. H. (1992). *Organizational culture and leadership* (2nd ed.). San Francisco, CA: Jossey Bass.

Schenkman, B. N., & Nilsson, M. E. (2011). Human echolocation: Pitch versus loudness information. *Perception*, *40*(7), 840–852. doi:10.1068/p6898

Schiller, F., & Prpich, G. (2014). Learning to organise risk management in organisations: What future for enterprise risk management? *Journal of Risk Research*, *17*(8), 999–1017. doi:10.1080/13669877.2013.841725

Schindler, P. L., & Thomas, C. C. (1993). The structure of interpersonal trust in the workplace. *Psychological Reports*, *73*(2), 563–573. doi:10.2466/pr0.1993.73.2.563

Schmidt, F. L., & Hunter, J. E. (1998). The validity and utility of selection methods in personnel psychology: Practical and theoretical implications of 85 years of research findings. *Psychological Bulletin*, *124*(2), 262–274. doi:10.1037/0033-2909.124.2.262

Schmidt-Hieber, C., & Häusser, M. (2013). Cellular mechanisms of spatial navigation in the medial entorhinal cortex. *Nature Neuroscience*, *16*(3), 325–331. doi:10.1038/nn.3340

Schneider, B. (Ed.). (1990). *Organizational climate and culture*. San Francisco, CA: Jossey-Bass.

Schneider, B., White, S. S., & Paul, M. C. (1998). Linking service climate and customer perceptions of service quality: Test of a causal model. *Journal of Applied Psychology*, *83*(2), 150–163. doi:10.1037/0021-9010.83.2.150

Schömig, N., & Metz, B. (2013). Three levels of situation awareness in driving with secondary tasks. *Safety Science*, *56*, 44–51. doi:10.1016/j.ssci.2012.05.029

Schriesheim, C. A., Castro, S. L., & Cogliser, C. C. (1999). Leader-member exchange (LMX) research: A comprehensive review of theory, measurement, and data-analytic practices. *The Leadership Quarterly*, *10*(1), 63–113. doi:10.1016/S1048-9843(99)80009-5

Schriesheim, C. A., & Neider, L. L. (1996). Path-goal leadership theory: The long and winding road. *The Leadership Quarterly*, *7*(3), 317–321. doi:10.1016/S1048-9843(96)90023-5

Schriesheim, C. A., Tepper, B. J., & Tetrault, L. A. (1994). Least preferred co-worker score, situational control and leadership effectiveness: A meta analysis of contingency model performance predictions. *Journal of Applied Psychology*, *79*(4), 561–573. doi:10.1037/0021-9010.79.4.561

Schriesheim, C. A., Wu, J. B., & Scandura, T. A. (2009). A meso measure? Examination of the levels of analysis of the Multifactor Leadership Questionnaire (MLQ). *The Leadership Quarterly*, *20*(4), 604–616. doi:10.1016/j.leaqua.2009.04.005

Schwartz, B. S. (1991). Epidemiology and its application to olfactory dysfunction. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 307–334). Berlin, Germany: Springer.

Schwebel, D. C., Severson, J., Ball, K. K., & Rizzo, M. (2006). Individual difference factors in risky driving: The roles of anger/hostility, conscientiousness, and sensation-seeking. *Accident Analysis & Prevention*, *38*(4), 801–810. doi:10.1016/j.aap.2006.02.004

Scott-Parker, B., Watson, B., King, M. J., & Hyde, M. K. (2012). The influence of sensitivity to reward and punishment, propensity for sensation seeking, depression and anxiety on the risky behaviour of novice drivers: A path model. *British Journal of Psychology*, *103*(2), 248–267. doi:10.1111/j.2044-8295.2011.02069.x

Scott-Parker, B., Watson, B., King, M. J., & Hyde, M. K. (2013). A further exploration of sensation seeking propensity, reward sensitivity, depression, anxiety, and the risky behaviour of young novice drivers in a structural equation model. *Accident Analysis & Prevention*, *50*, 465–471. doi:10.1016/j.aap.2012.05.027

Segerstrom, S. C. (2007). Stress, energy, and immunity: An ecological view. *Current Directions in Psychological Science*, *16*(6), 326–330. doi:10.1111/j.1467-8721.2007.00522.x

Segerstrom, S. C., & Miller, G. E. (2004). Psychological stress and the human immune system: A meta-analytic study of 30 years of inquiry. *Psychological Bulletin*, *130*(4), 601–630. doi:10.1037/0033-2909.130.4.601

Semin, G. R., & de Groot, J. H. B. (2013). The chemical bases of human sociality. *Trends in Cognitive Sciences*, *7*(9), 427–429. doi:10.1016/j.tics.2013.05.008

Senge, P. (1990). *The fifth discipline*. New York, NY: Doubleday.

Senge, P., Kleiner, A., Roberts, C., Ross, R. Roth, G., & Smith, B. (1999). *The dance of change: The challenges of sustaining momentum in learning organizations*. London, UK: N Brealey Publishing.

Sergent, C., & Dehaene, S. (2004). Neural processes underlying conscious perception: Experimental findings and a global neuronal workspace framework. *Journal of Physiology-Paris*, *98*(4), 374–384. doi:10.1016/j.jphysparis.2005.09.006

Settoon, R. P., Bennett, N., & Liden, R. C. (1996). Social exchange in organizations: Perceived organizational support, leader–member exchange, and employee reciprocity. *Journal of Applied Psychology*, *81*(3), 219–227. doi:10.1037/0021-9010.81.3.219

Shamir, B., House, R. J., & Arthur, M. B. (1993). The motivational effects of charismatic leadership: A self-concept theory. *Organization Science*, *4*(4), 577–594. doi:10.1287/orsc.4.4.577

Shanafelt, T. D., Balch, C. M., Bechamps, G., Russell, T., Dyrbye, L., Satele, D., … & Freischlag, J. (2010). Burnout and medical errors among American surgeons. *Annals of Surgery*, *251*(6), 995–1000. doi:10.1097/SLA.0b013e3181bfdab3

Shannon, H. S., Mayr, J., & Haines, T. (1997). Overview of the relationship between organizational and workplace factors and injury rates. *Safety Science*, *26*(3), 201–217. doi:10.1016/S0925-7535(97)00043-X

Shavit, T., Shahrabani, S., Benzion, U., & Rosenboim, M. (2013). The effect of a forest fire disaster on emotions and perceptions of risk: A field study after the Carmel fire. *Journal of Environmental Psychology*, *36*, 129–135. doi:10.1016/j.jenvp.2013.07.018

Shaw, L. (1965). The practical use of projective personality tests as accident predictors. *Traffic Safety Research Review*, *9*(2), 34–72.

Shaw, L., & Sichel, H. S. (1971). *Accident proneness*. Oxford, UK: Pergamon.

She, S-x., Lu, Q., & Ma, C-q. (2012). A probability–time&space trade-off model in environmental risk perception. *Journal of Risk Research*, *15*(2), 223–234. doi:10.1080/13669877.2011.634515

Shepherd, G. M. (2004). The human sense of smell: Are we better than we think? *PLoS Biology*, *2*(5), 572–575. doi:10.1371/journal.pbio.0020146

Shepherd, G. M. (2005). Outline of a theory of olfactory processing and its relevance to humans. *Chemical Senses*, *30*(Suppl. 1), i3–i5. doi:10.1093/chemse/bjh085

Sherif, M. (1967). *Group conflict and cooperation: Their social psychology*. London, UK: Routledge.

Sherry, P. (1991). Person-environment fit and accident prediction. *Journal of Business and Psychology*, *5*(3), 411–416. doi:10.1007/BF01017711

Shipley, M., & Reyes, P. (1991). Anatomy of the human olfactory bulb and central olfactory pathways. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 29–60). Berlin, Germany: Springer.

Shirazi, S. M., Imran, H. M., & Akib, S. (2012). GIS-based DRASTIC method for groundwater vulnerability assessment: A review. *Journal of Risk Research*, *15*(8), 991–1011. doi:10.1080/13669877.2012.686053

Shorer, Z., Shaco-Levy, R., Pinsk, V., Kachko, L., & Levy, J. (2013). Variation of muscular structure in congenital insensitivity to pain and anhidrosis. *Pediatric Neurology*, *48*(4), 311–313. doi:10.1016/j.pediatrneurol.2012.12.015

Siegel, D. J. (2001). Toward an interpersonal neurobiology of the developing mind: Attachment relationships, "mindsight," and neural integration. *Infant Mental Health Journal*, *22*(1–2), 67–94. doi:10.1002/1097-0355(200101

Siegel, D. J. (2009). Mindful awareness, mindsight, and neural integration. *The Humanistic Psychologist*, *37*(2), 137–158. doi:10.1080/08873260902892220

Siegel, D. J. (2010). *Mindsight: Our seventh sense*. New York, NY: Bantam.

Siegrist, M. (2012). Special issue on the conference 'Environmental Decisions: Risks and Uncertainties' in Monte Verità, Switzerland. *Journal of Risk Research*, *15*(3), 235–236. doi:10.1080/13669877.2012.657222

Signorino, G. (2012). Proximity and risk perception: Comparing risk perception 'profiles' in two petrochemical areas of Sicily (Augusts and Milazzo). *Journal of Risk Research*, *15*(10), 1223–1243. doi:10.1080/13669877.2012.670129

Silva, R. A., West, J. J., Zhang, Y-q., Anenberg, S. C., Lamarque, J-F., Shindell, D. T., … Zeng, G. (2013). Global premature mortality due to anthropogenic outdoor air pollution and the contribution of past climate change. *Environmental Research Letters*, *8*(3), 034005. doi:10.1088/1748-9326/8/3/034005

Simard, M., & Marchand, A. (1995). A multilevel analysis of organizational factors related to the taking of safety initiatives by work groups. *Safety Science*, *21*(2), 113–129.

Simard, M., & Marchand, A. (1997). Workgroups' propensity to comply with safety rules: The influence of micro–macro organizational factors. *Ergonomics*, *40*(2), 172–188. doi:10.1080/001401397188288

Simpson, S. A., Wadsworth, E. J. K., Moss, S. C., & Smith, A. P. (2005). Minor injuries, cognitive failures and accidents at work: Incidence and associated features. *Occupational Medicine*, *55*(2), 99–108. doi:10.1093/occmed/kqi035

Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science*, *303*(5661), 1157–1162. doi:10.1126/science.1093535

Singer, W. (1998). Consciousness and the structure of neuronal representations. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *353*(1377), 1829–1840. doi:10.1098/rstb.1998.0335

Singh, V. (2013). Dual conception of risk in the Iowa Gambling Task: Effects of sleep deprivation and test-retest gap. *Frontiers in Psychology*, *4*, 628. doi:10.3389/fpsyg.2013.00628

Sipilä, J., Auerkari, P., Heikkilä, A-M., & Krause, U. (2013). Emerging risk of autoignition and fire in underground coal storage. *Journal of Risk Research*, *16*(3–4), 447–457. doi:10.1080/13669877.2012.729525

Sipilä, J., Auerkari, P., Malmén, Y., Heikkilä, A-M., Vela, I., & Krause, U. (2013). Experience and the unexpected: Risk and mitigation issues for operating underground storage silos for coal-fired power plant. *Journal of Risk Research*, *16*(3–4), 487–500. doi:10.1080/13669877.2012.729530

Sirotin, Y. B., & Das, A. (2009). Anticipatory haemodynamic signals in sensory cortex not predicted by local neuronal activity. *Nature*, *457*(7228), 475–479. doi:10.1038/nature07664

Sitkin, S. B., & Weingart, L. R. (1995). Determinants of risky decision-making behavior: A test of the mediating role of risk perceptions and propensity. *Academy of Management Journal*, *38*(6), 1573–1592. doi:10.2307/256844

Siu, O.-l., Phillips, D. R., & Leung, T.-w. (2004). Safety climate and safety performance among construction workers in Hong Kong: The role of psychological strains as mediators. *Accident Analysis and Prevention*, *36*(3), 359–366. doi:10.1016/S0001-4575(03)00016-2

Skinner, D. J. C., Rocks, S. A., & Pollard, S. J. T. (2014). A review of uncertainty in environmental risk: Characterising potential natures, locations and levels. *Journal of Risk Research*, *17*(2), 195–219. doi:10.1080/13669877.2013.794150

Slovic, P. (2010). *The feeling of risk*. London, UK: Earthscan.

Slovic, P., Peters, E., Finucane, M., & Macgregor, D. (2005). Affect, risk, and decision making. *Health Psychology*, *24*(Suppl. 4), S35–S40. doi:10.1037/0278-6133.24.4.S35

Small, D. M., Gerber, J. C., Mak, Y. E., & Hummel, T. (2005). Differential neural responses evoked by orthonasal versus retronasal odorant perception in humans. *Neuron*, *47*(4), 593–605. doi:10.1016/j.neuron.2005.07.022

Smallegange, R. C., van Gemert, G. J., van de Vegte-Bolmer, M., Gezan, S., Takken, W., Sauerwein, R. W., & Logan, J. G. (2013). Malaria infected mosquitoes express enhanced attraction to human odor. *PloS One*, *8*(5), e63602. doi:10.1371/journal.pone.0063602

Smeed, R. J. (1960). Proneness of drivers to road accidents. *Nature*, *186*(4271), 273–275.

Smillie, L. D., Pickering, A. D., & Jackson, C. J. (2006). The new reinforcement sensitivity theory: Implications for personality measurement. *Personality and Social Psychology Review*, *10*(4), 320–335. doi:10.1207/s15327957pspr1004_3

Smith, A. P. (1992). Time of day and performance. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance Vol. 3: State and trait* (pp. 215–235). London, UK: Academic Press.

Smith, D. H., & Meaney, D. F. (2002). Roller coasters, G forces, and brain trauma: On the wrong track? *Journal of Neurotrauma*, *19*(10), 1117–1120. doi:10.1089/08977150260337921

Smith, D. I., & Kirkham, R. W. (1981). Relationship between some personality characteristics and driving record. *British Journal of Social Psychology*, *20*(4), 229–231. doi:10.1111/j.2044-8309.1981.tb00491.x

Smith, D. L., & Heckert, T. M. (1998). Personality characteristics and traffic accidents of college students. *Journal of Safety Research*, *29*(3), 163–169. doi:10.1016/S0022-4375(98)00012-7

Smith, D. V., & Seiden, A. M. (1991). Olfactory dysfunction. In D. G. Laing, R. L. Doty, & W. Briepohl (Eds.), *The human sense of smell* (pp. 283–305). Berlin, Germany: Springer.

Smith, K., & Hancock, P. A. (1995). Situation awareness is adaptive, externally directed consciousness. *Human Factors, 37*(1), 137–148. doi:10.1518/001872095779049444

Smith, N. A. (2005). Light and lighting. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 268–285). Oxford, UK: Blackwell.

Smith, T. (2015). Nuclear licensing in the United States: Enhancing public confidence in the regulatory process. *Journal of Risk Research, 18(8),* 1099–1112. doi:10.1080/13669877.2014.919520

Smith, V. L. (1975). The primitive hunter culture, pleistocene extinction, and the rise of agriculture. *Journal of Political Economy, 83*(4), 727–756.

Sneddon, A., Mearns, K., & Flin, R. (2013). Stress, fatigue, situation awareness and safety in offshore drilling crews. *Safety Science, 56,* 80–88. doi:10.1016/j.ssci.2012.05.027

Snyder, L. A., Krauss, A. D., Chen, P. Y., Finlinson, S., & Huang, Y.-H. (2008). Occupational safety: Application of the job demand–control support model. *Accident Analysis and Prevention, 40*(5), 1713–1723. doi:10.1016/j.aap.2008.06.008

Soon, J. M., & Baines, R. N. (2012). Farm food safety and diseases risk assessments: Case studies from the horticultural and salmonoid farms. *Journal of Risk Research, 15*(4), 389–403. doi:10.1080/13669877.2011.634518

Sorensen, L. J., & Stanton, N. A. (2013). Y is best: How distributed situational awareness is mediated by organisational structure and correlated with task success. *Safety Science, 56,* 72–79. doi:10.1016/j.ssci.2012.05.026

Soule, B. (2012). Coupled seismic and socio-political crises: The case of Puerto Aysen in 2007. *Journal of Risk Research, 15*(1), 21–37. doi:10.1080/13669877.2011.591498

Sparks, K., & Cooper, C. L. (1999). Occupational differences in the work–strain relationship: Towards the use of situation–specific models. *Journal of Occupational and Organizational Psychology, 72*(2), 219–229. doi:10.1348/096317999166617

Sparks, K., Faragher, B., & Cooper, C. L. (2001). Well–being and occupational health in the 21st century workplace. *Journal of Occupational and Organizational Psychology, 74*(4), 489–509. doi:10.1348/096317901167497

Spector, P. E. (2000). A control theory of the job stress process. In C. L. Cooper (Ed.), *Theories of organizational stress* (pp. 153–169). New York, NY: Oxford University Press.

Spector, P. E., & O'Connell, B. J. (1994). The contribution of personality traits, negative affectivity, locus of control and Type A to the subsequent reports of job stressors and job strains. *Journal of Occupational and Organizational Psychology, 67*(1), 1–12. doi:10.1111/j.2044-8325.1994.tb00545.x

Spector, P. E., Zapf, D., Chen, P., & Frese, M. (2000). Why negative affectivity should not be controlled in job stress research: Don't throw the baby out with the bath water. *Journal of Organizational Behavior, 21*(1), 79–95.

Spence, C., & Ho, C. (2008). Tactile and multisensory spatial warning signals for drivers. *IEEE Transactions on Haptics, 1*(2), 121–129. doi:10.1109/ToH.2008.14

Spence, C., & McDonald, J. (2004). The cross-modal consequences of the exogenous spatial orienting of attention. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 1–25). Cambridge, MA: MIT Press.

Spieglhalter , D. (2009, 15 August). Don't react, think. *New Scientist*, 20–21.

Spreitzer, G. M. (1995). Psychological empowerment in the workplace: Dimensions, measurement, and validation. *The Academy of Management Journal, 38*(5), 1442–1465. doi:10.2307/256865

Squire, L. R., Clark, R. E., & Bayley, P. J. (2004). Medial temporal lobe function and memory. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 691–708). Cambridge, MA: MIT Press.

Squire, L. S., & Knowlton, B. J. (2000). The medial temporal lobe, the hippocampus, and the memory systems of the brain. In Gazzaniga, M. S. (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 765–779). Cambridge, MA: MIT Press.

Sridharan, D., Levitin, D. J., & Menon, V. (2008). A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks. *Proceedings of the National Academy of Sciences, 105*(34), 12569–12574. doi:10.1073pnas.0800005105

Srivastava, S., John, O. P., Gosling, S. D., & Potter, J (2003). Development of personality in early and middle adulthood: Set like plaster or persistent change? *Journal of Personality and Social Psychology*, *84*(5), 1041–1053. doi:10.1037/0022-3514.84.5.1041

Stallones, L., & Kraus, J. F. (1993). The occurrence and epidemiologic features of alcohol–related occupational injuries. *Addiction*, *88*(7), 945–951. doi:10.1111/j.1360-0443.1993.tb02112.x

Stanojevic, P., Orlic, B., Misita, M., Tatalovic, N., & Lenkey, G. B. (2013). Online monitoring and assessment of emerging risk in conventional industrial plants: Possible way to implement integrated risk management approach and KPIs. *Journal of Risk Research*, *16*(3–4), 501–512. doi:10.1080/13669877.2012.729531

Stanton, N. A., Chambers, P. R. G., & Piggott, J. (2001). Situational awareness and safety. *Safety Science*, *39*(3), 189–204. doi:10.1016/S0925-7535(01)00010-8

Stanton, N. A., Matthews, G., Graham, N. C., & Brimelow, C. (1991). The OPQ and the big five. *Journal of Managerial Psychology*, *6*(1), 25–27. doi:10.1108/02683949110140750

Stanton, N. A., Salmon, P. M., Walker, G. H., & Jenkins, D. (2009). Genotype and phenotype schemata and their role in distributed situation awareness in collaborative systems. *Theoretical Issues in Ergonomics Science*, *10*(1), 43–68. doi:10.1080/14639220802045199

Stanton, N. A., Walker, G. H., Young, M. S., Kazi, T., & Salmon, P. M. (2007). Changing drivers' minds: The evaluation of an advanced driver coaching system. *Ergonomics*, *50*(8), 1209–1234. doi:10.1080/00140130701322592

Staw, B. M., & Barsade, S. G. (1993). Affect and managerial performance: A test of the sadder-but-wiser vs. happier-and-smarter hypotheses. *Administrative Science Quarterly*, *38*(2), 304–331.

Stefanucci, J. K., & Proffitt, D. R. (2009). The roles of altitude and fear in the perception of height. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2), 424–438. doi:10.1037/a0013894

Stefanucci, J. K., Proffitt, D. R., Clore, G. L., & Parekh, N. (2008). Skating down a steeper slope: Fear influences the perception of geographical slant. *Perception*, *37*(2), 321–323. doi:10.1068/p5796

Steffy, B. D., Jones, J. W., Murphy. L. R., & Kunz, L. (1986). A demonstration of the impact of stress abatement programs on reducing employees' accidents and their costs. *American Journal of Health Promotion*, *1*(2), 25–32. doi:10.4278/0890-1171-1.2.25

Stegen, K. S., Gilmartin, P., & Carlucci, J. (2012). Terrorists versus the Sun: Desertec in North Africa as a case study for assessing risks. *Risk Management: A Journal of Risk, Crisis and Disaster*, *14*(1), 3–26. doi:10.1057/rm.2011.15

Stein, B. E., Jiang, W., & Stanford, T. R. (2004). Multisensory integration in single neurons of the midbrain. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 243–264). Cambridge, MA: MIT Press.

Stein, B. E., Wallace, M. T., & Stanford, T. R. (2000). Merging sensory signals in the brain: The development of multi-sensory integration in the superior colliculus. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (2nd ed., pp. 55–71). Cambridge, MA: MIT Press.

Steiner, I. D. (1972). *Group process and productivity*. New York, NY: Academic Press.

Steiner, I .D. (1982). Heuristic models of groupthink. In H. Brandstatter, J. H. Davis, & G. Stocker–Kreichgauer (Eds.), *Group decision making*. (pp. 503–524). New York, NY: Academic Press.

Stephan, E., Pardo, J. V., Faris, P. L., Hartman, B. K., Kim, S. W., Ivanov, E. H., … Goodale, R. L. (2003). Functional neuroimaging of gastric distention. *Journal of Gastrointestinal Surgery*, *7*(6), 740–749. doi:10.1016/S1091-255X(03)00071-4

Stephen, I. D., Mahmut, M. K., Case, T. I., Fitness, J., & Stevenson, R. J. (2014). The uniquely predictive power of evolutionary approaches to mind and behavior. *Frontiers in Psychology*, *5*, 1372. doi:10.3389/fpsyg.2014.01372

Stephens, B. R., Granados, K., Zderic, T. W., Hamilton, M. T., & Braun, B. (2011). Effects of 1 day of inactivity on insulin action in healthy men and women: Interaction with energy intake. *Metabolism, Clinical and Experimental*, *60*(7), 941–949. doi:10.1016/j.metabol.2010.08.014

Stetz, T. A., Stetz, M. C., & Bliese, P. D. (2006). The importance of self-efficacy in the moderating effects of social support on stressor–strain relationships. *Work & Stress*, *20*(1), 49–59. doi:10.1080/02678370600624039

Steven, M. S., & Blakemore, C. (2004). Cortical plasticity in the adult human brain. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 1243–1254). Cambridge, MA: MIT Press.

Stevenson, R. J., & Boakes, R. A. (2004). Sweet and sour smells: Learned synesthesia between the senses of taste and smell. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 69–83). Cambridge, MA: MIT Press.

Stogdill, R. M. (1974). *Handbook of leadership*. New York, NY: Free Press.

Stokols, D., McMahan, S., Chiltheroe, H. C. Jr., & Wells, M. (2001). Enhancing corporate compliance with worksite safety and health legislation. *Journal of Safety Research*, *32*(4), 441–463. doi:10.1016/S0022-4375(01)00063-9

Størseth, F. (2006). Changes at work and employee reactions: Organizational elements, job insecurity, and short-term stress as predictors for employee health and safety. *Scandinavian Journal of Psychology*, *47*(6), 541–550. doi:10.1111/j.1467-9450.2006.00548.x

Strayer, D. L., Cooper, J. M., Turrill, J., Coleman, J., Medieros-Ward, N., & Biondi, F. (2013). *Measuring cognitive distraction in the automobile*. Washington, DC: AAA Foundation for Traffic Safety.

Ström, M., Koivisto, R., & Andersson, D. (2013). UML modelling concepts of HAZOP to enhance the ability to identify emerging risks. *Journal of Risk Research*, *16*(3–4), 421–432. doi:10.1080/13669877.2012.729521

Strybel, T. Z., Vu, K.-P. L., Chiappe, D., Battiste, V., Johnson, W., & Dao, A.-Q. V. (2011). *Metrics for situation awareness, workload and performance: Manual for online probe administration*. (Technical Report NASA/TM–215991). Washington, DC: National Aeronautics and Space Administration.

Stuttaford, T. (1999, September 14). Addicted to risk? It's your novelty gene. *The Times*, p. 38.

Suchman, E. A. (1970). Accidents and social deviance. *Journal of Health and Social Behavior*, *11*(1), 4–15.

Suetens, P. (2009). *Fundamentals of medical imaging* (2nd ed.). Cambridge, UK: Cambridge University Press.

Suhr, V. W. (1961). Personality and driving efficiency. *Perceptual and Motor Skills*, *12*(1), 34–34. doi:10.2466/pms.1961.12.1.34

Sullman, M. J. M., Meadows, M. L., & Pajo, K. B. (2002). Aberrant driving behaviours amongst New Zealand truck drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *5*(3), 217–232. doi:10.1016/S1369-8478(02)00019-0

Sulloway, F. J., & Zweigenhaft, R. L. (2010). Birth order and risk taking in athletics: A meta-analysis and study of major league baseball. *Personality and Social Psychology Review*, *14*(4), 402–416. doi:10.1177/1088868310361241

Sun, H.-Y., Rao, L-L., Zhou, K., & Li, S. (2014). Formulating an emergency plan based on expectation-maximization is one thing, but applying it to a single case is another. *Journal of Risk Research*, *17*(7), 785–814. doi:10.1080/13669877.2013.816333

Sutaria, A. (2014). Placing the Indian civil nuclear liability regime in context: The extent of supplier's liability. *Journal of Risk Research*, *17*(1), 97–113. doi:10.1080/13669877.2013.822922

Sutherland, V. J., & Cooper, C. L. (1990). *Understanding stress*. London, UK: Chapman & Hall.

Sutherland, V. J., & Cooper, C. L. (1991). *Stress and accidents in the offshore oil and gas industry*. Houston, TX: Gulf.

Suzuki, I. (2012). Effects of sense of direction on Internet skill and cognitive maps of the Web. *Computers in Human Behavior*, *28*(1), 120–128. doi:10.1016/j.chb.2011.08.018

Symmonds, M., Moran, R. J., Wright, N. D., Bossaerts, P., & Barnes, G. (2013). The chronometry of risk processing in the human cortex. *Frontiers in Neuroscience*, *7*, 146. doi:10.3389/fnins.2013.00146

Taira, K. (1996). Compatibility of human resource management, industrial relations, and engineering under mass production and lean production: An exploration. *Applied Psychology: An International Review*, *45*(2), 97–117. doi:10.1111/j.1464-0597.1996.tb00753.x

Takeuchi, R., Yun, S., & Wong, K. F. E. (2011). Social influence of a coworker: A test of the effect of employee and coworker exchange ideologies on employees' exchange qualities. *Organizational Behavior and Human Decision Processes*, *115*(2), 226–237. doi:10.1016/j.obhdp.2011.02.004

Tammepuu, A., & Sepp, K. (2013). Emergency risk assessment: The Estonian approach. *Journal of Risk Research*, *16*(2), 169–193. doi:10.1080/13669877.2012.726237

Tanaka, Y. (2013). Attitude gaps between conventional plant breeding crops and genetically modified crops, and psychological models determining the acceptance of the two crops. *Journal of Risk Research*, *16*(1), 69–80. doi:10.1080/13669877.2012.726236

Tandonnet, C., Burle, B., Vidal, F., & Hasbroucq, T. (2014). Tactile stimulations and wheel rotation responses: Toward augmented lane departure warning systems. *Frontiers in Psychology*, *5*, 1045. doi:10.3389/fpsyg.2014.01045

Tang, T. Z., DeRubeis, R. J., Hollon, S. D., Amsterdam, J., Shelton, R., & Schalet, B. (2009). Personality change during depression treatment: A placebo-controlled trial. *Archives of General Psychiatry*, *66*(12), 1322–1330. doi:10.1001/archgenpsychiatry.2009.166

TangenCognitionLab. (July 7, 2011). *Shocking illusion—Pretty girls turn ugly!* https://www.youtube.com/watch?v=wM6lGNhPujE. Accessed July 3, 2015.

TangenCognitionLab. (May 14, 2012). *Shocking illusion—Pretty celebrities turn ugly!* https://www.youtube.com/watch?v=VT9i99D_9gI. Accessed July 3, 2015.

Tavares, A. O., & dos Santos, P. P. (2014). Re-scaling risk governance using local appraisal and community involvement. *Journal of Risk Research*, *17*(7), 923–949. doi:10.1080/13669877.2013. 822915

Tayama, J., Li, J., & Munakata, M. (2015). Working long hours is associated with higher prevalence of diabetes in urban male Chinese workers: The Rosai Karoshi study. *Stress and Health*. doi:10.1002/smi.2580

Taylor, R. M. (1990). *Situation Awareness Rating Technique (SART): The development of a tool for aircrew systems design* (AGARD-CP-478). Advisory Group for Aerospace Research and Development, Neuilly-sur-Seine, France.

Taylor, S. E., & Brown, J. D. (1988). Illusion and well-being: A social psychological perspective on mental health. *Psychological Bulletin*, *103*(2), 193–210. doi:10.1037/0033-2909.103.2.193

Teed, D. N., Knapp, A., Hagen, M., Lee, J. T., & Pardo, J. V. (2009). Human visual-processing of food-related stimuli in hunger and satiated states. *NeuroImage*, *47*(Suppl. 1), S39–S41. doi:10.1016/S1053-8119(09)72158-5

Teki, S., & Griffiths, T. D. (2012). A unified model for the neural bases of auditory time perception. In E. Cambouropoulos, C. Tsougras, P. Mavromatis, & K. Pastiadis (Eds.), *Proceedings of the 12th International Conference on Music Perception and Cognition* (pp. 973–979), July 23–28, Thessaloniki, Greece.

Teki, S., Grube, M., & Griffiths, T. D. (2011). A unified model of time perception accounts for duration-based and beat-based timing mechanisms. *Frontiers in Integrative Neuroscience*, *5*, 90. doi:10.3389/fnint.2011.00090

Tekleab, A. G., Quigley, N. R., & Tesluk, P. E. (2009). A longitudinal study of team conflict, conflict management, cohesion, and team effectiveness. *Group Organization Management*, *34*(2), 170–205. doi:10.1177/1059601108331218

Teng, S., Puri, A., & Whitney, D. (2011). Cross-modal transfer of object information in human echolocation (abstract). *i-Perception*, *2*(8), 894.

Terra, N. (1995). The prevention of job stress by redesigning jobs and implementing self–regulating teams. In L. R. Murphy, J. J. Hurrell Jr., S. L. Sauter, & G. P. Keita (Eds.), *Job stress interventions* (pp. 265–281). Washington, DC: American Psychological Association.

Terracciano, A., McCrae, R. R., & Costa, P. T. Jr. (2010). Intra-individual change in personality stability and age. *Journal of Research in Personality*, *44*(1), 31–37. doi:10.1016/j.jrp.2009.09.006

Terry, D. (1991). Coping resources and situational approaches as predictors of coping behavior. *Personality and Individual Differences*, *12*(10), 1031–1047. doi:10.1016/0191-8869(91)90033-8

Tesluk, P., & Quigley, N. R. (2003). Group and normative influences on health and safety: Perspectives from taking a broad view on team effectiveness. In D. A. Hofmann & L. E. Tetrick (Eds.), *Health and safety in organizations: A multilevel perspective* (pp. 131–172). San Francisco, CA: Jossey–Bass.

Tetlock, P. E. (1979). Identifying victims of groupthink from public statements of decision makers. *Journal of Personality and Social Psychology*, *37*(8), 1314–1324. doi:10.1037/0022-3514.37.8.1314

Tett, R. P., Jackson, D. N., & Rothstein, M. (1991). Personality measures as predictors of job performance: A meta-analytic review. *Personnel Psychology*, *44*(4), 703–742. doi:10.1111/j.1744-6570.1991.tb00696.x

Thaler, L., Arnott, S. R., & Goodale, M. A. (2011). Neural correlates of natural human echolocation in early and late blind echolocation experts. *PLoS One*, *6*(5), e20162. doi:10.1371/journal.pone.0020162

Thaler, R. H., & Sunstein, C. R. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. Newhaven, CT: Yale University Press.

Tham, W. W. P., Stevenson, R. J., & Miller, L. A. (2011). The role of the mediodorsal thalamic nucleus in human olfaction, *Neurocase: The Neural Basis of Cognition*, *17*(2), 148–159. doi:10.1080/13554794.2010.504728

Thayer, R. E. (1987). Problem perception, optimism, and related states as a function of time of day (diurnal rhythm) and moderate exercise: Two arousal systems in interaction. *Motivation and Emotion*, *11*(1), 19–36. doi:10.1007/BF00992211

Theorell, T., Emdad, R., Arnetz, B., & Weingarten, A. (2001). Employee effects of an educational program for managers at an insurance company. *Psychosomatic Medicine*, *63*(5), 724–733.

Thiffault, P., & Bergeron, J. (2003). Fatigue and individual differences in monotonous simulated driving. *Personality and Individual Differences*, *34*(1), 159–176. doi:10.1016/S0191-8869(02)00119-8

Thomas, K. W., & Velthouse, B. A. (1990). Cognitive elements of empowerment: An "interpretive" model of intrinsic task motivation. *The Academy of Management Review*, *15*(4), 666–681. doi:10.5465/AMR.1990.4310926

Thompson, B., Kirk–Brown, A., & Brown, D. (1998). *The impact of policewomen's work stress on family members: A report for the Queensland Police Service*. Brisbane, QLD: Griffith University.

Thompson, B., Kirk–Brown, A., & Brown, D. (2001). Women police: The impact of work stress on family members. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload and fatigue: Theory, research and practice* (pp. 200–210). Mahwah, NJ: Erlbaum.

Thompson, R. C., Hilton, T. F., & Witt, L. A. (1998). Where the safety rubber meets the shop floor: A confirmatory model of management influence on workplace safety. *Journal of Safety Research*, *29*(1), 15–24. doi:10.1016/S0022-4375(97)00025-X

Tilley, A., & Brown, S. (1992). Sleep deprivation. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance Vol. 3: State and trait*. (pp. 237–259). London, UK: Academic Press.

Timmerer, C., & Müller, K. (2010). Immersive future media technologies: From 3D video to sensory experiences. *MM'10*, pp. 1781–1782. Firenze, Italy, October 25–29. ACM 978-1-60558-933-6/10/10.

Tipper, S. P. (2004). Attention and action. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 619–629). Cambridge, MA: MIT Press.

Tippett, W. J., & Sergio, L. E. (2006). Visuomotor integration is impaired in early stage Alzheimer's Disease. *Brain Research*, *1102*(1), 92–102. doi:10.1016/j.brainres.2006.04.049

Tjosvold, D., Wedley, W. C., & Field, R. H. (1986). Constructive controversy, the Vroom-Yetton model, and managerial decision-making. *Journal of Organizational Behavior*, *7*(2), 125–138. doi:10.1002/job.4030070205

Toft, B. (1992, April). *Changing a safety culture: Decree, prescription or learning*. Paper presented at Conference on Risk, Management and Safety Culture, London, UK: London Business School.

Toglia, J., & Kirk, U. (2000). Understanding awareness deficits following brain injury. *Neurorehabilitation*, *15*(1), 57–70.

Tomás, J. M., Meliá, J. L., & Oliver, A. (1999). A cross–validation of a structural equation model of accidents: Organizational and psychological variables as predictors of work safety. *Work & Stress*, *13*(1), 49–58. doi:10.1080/026783799296183

Tononi, G. (2004). An information integration theory of consciousness. *BMC Neuroscience*, *5*(1), 42–63. doi:10.1186/1471-2202-5-42

Torrubia, R., Àvila, C., Moltó, J., & Caseras, X. (2001). The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. *Personality and Individual Differences*, *31*(6), 837–862. doi:10.1016/S0191-8869(00)00183-5

Tortosa-Edo, V., López-Navarro, M. A., & Llorens-Monzonís, J. (2015). Antecedent factors of the need for information regarding petrochemical complex hazards. *Journal of Risk Research*. doi:10.1080/13669877.2014.961509

Tortosa-Edo, V., López-Navarro, M. A., Llorens-Monzonís, J., & Rodríguez-Artola, R. M. (2014). The antecedent role of personal environmental values in the relationships among trust in companies, information processing and risk perception. *Journal of Risk Research*, *17*(8), 1019–1035. doi:10.1080/13669877.2013.841726

Tost, H., & Meyer-Lindenberg, A. (2012). Puzzling over schizophrenia: Schizophrenia, social environment and the brain. *Nature Medicine*, *18*(2), 211–213. doi:10.1038/nm.2671

Totterdell, P., Wood, S., & Wall, T. (2006). An intra-individual test of the demands-control model: A weekly diary study of psychological strain in portfolio workers. *Journal of Occupational and Organizational Psychology*, *79*(1), 63–84. doi:10.1348/096317905X52616

Townsend, E., Spence, A., & Knowles, S. (2014). Investigating the operation of the affect heuristic: Is it an associative construct? *Journal of Risk Research*, *17*(3), 299–315. doi:10.1080/13669877.2013.808687

Townsend, J., Phillips, J. S., & Elkins, T. J. (2000). Employee retaliation: The neglected consequence of poor leader-member exchange relations. *Journal of Occupational Health Psychology*, *5*(4), 457–463. doi:10.1037/1076-8998.5.4.457

Trimpop, R. M. (1994). *The Psychology of risk taking behavior*. Amsterdam, the Netherlands: North-Holland.

Trimpop, R. M., Kirkcaldy, B., Athanasou, J., & Cooper, C. L. (2000). Individual differences in working hours, work perceptions and accident rates in veterinary surgeries. *Work & Stress*, *14*(2), 181–188. doi:10.1080/026783700750051685

Trist, E. L., Higgin, G. W., Murray, H., & Pollock, A. B. (1963). *Organizational choice*. London, UK: Tavistock.

Trist, E. L., Susman, G. I., & Brown, G. R. (1977). An experiment in autonomous working in an American underground coal mine. *Human Relations*, *30*(3), 201–236. doi:10.1177/001872677703000301

Treisman, A. (2004). Psychological issues in selective attention. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 529–544). Cambridge, MA: MIT Press.

Tsagarakis, K. P., Menegaki, A. N., Siarapi, K., & Zacharopoulou, F. (2013). Safety alerts reduce willingness to visit parks irrigated with recycled water. *Journal of Risk Research*, *16*(2), 133–144. doi:10.1080/13669877.2012.726246

Tsakiris, M., Tajadura-Jiménez, A., & Costantini, M. (2011). Just a heartbeat away from one's body: Interoceptive sensitivity predicts malleability of body-representations. *Proceedings of The Royal Society B: Biological Sciences*, *278*(1717), 2470–2476. doi:10.1098/rspb.2010.2547

Tse, P. U., Intriligator, J., Rivest, J., & Cavanagh, P. (2004). Attention and the subjective expansion of time. *Perception & Psychophysics*, *66*(7), 1171–1189. doi:10.3758/BF03196844

Tucker, S., Chmiel, N., Turner, N., Hershcovis, M. S., & Stride, C. B. (2008). Perceived organizational support for safety and employee safety voice: The mediating role of coworker support for safety. *Journal of Occupational Health Psychology*, *13*(4), 319–330. doi:10.1037/1076-8998.13.4.319

Tupes, E. C., & Christal, R. E. (1961). *Recurrent personality factors based on trait ratings* (pp. 61–97). ASD Technical Report. USAF.

Turner, B. A. (1991, April). The development of a safety culture. *Chemistry and Industry*, 241–243.

Turner, B. A., & Pidgeon, N. F. (1997). *Man-made disasters* (2nd ed.). London, UK: Butterworth–Heinemann.

Turner, B. A., Pidgeon, N. F., Blockley, D., & Toft, B. (1989). Safety culture: Its importance in future risk management. Position paper for the Second World Bank Workshop on Safety Control and Risk Management, Karlstad, Sweden, November.

Turner, M. M., Boudewyns, V., Kirby-Straker, R., & Telfer, J. (2013). A double dose of fear: A theory-based content analysis of news articles surrounding the 2006 cough syrup contamination crisis in Panama. *Risk Management: A Journal of Risk, Crisis and Disaster*, *15*(2), 79–99. doi:10.1057/rm.2012.13

Turner, N., Chmiel, N., Hershcovis, M. S., & Walls, M. (2010). Life on the line: Job demands, perceived co-worker support for safety, and hazardous work events. *Journal of Occupational Health Psychology*, *15*(4), 482–493. doi:10.1037/a0021004

Turner, N., Chmiel, N., & Walls, M. (2005). Railing for safety: Job demands, job control, and safety citizenship role definition. *Journal of Occupational Health Psychology*, *10*(4), 504–512. doi:10.1037/1076-8998.10.4.504

Turner, N., Hershcovis, M. S., Reich, T. C., & Totterdell, P. (2014). Work–family interference, psychological distress, and workplace injuries. *Journal of Occupational and Organizational Psychology*, *87*(4), 715–732. doi:10.1111/joop.12071

Turner, N., Stride, C. B., Carter, A. J., McCaughey, D., & Carroll, A. E. (2012). Job demands-control-support model and employee safety performance. *Accident Analysis and Prevention*, *45*, 811–817. doi:10.1016/j.aap.2011.07.005

Tveiten, C. K., & Schiefloe, P. M. (2014). Risk images in a changing high-risk industry. *Risk Management: A Journal of Risk, Crisis and Disaster*, *16*(1), 44–61. doi:10.1057/rm.2014.3

UK Cabinet Office (2010). *Applying behavioural insight to health*. London, UK: Cabinet Office, Behavioural Insights Team.

Ulleberg, P. (2002). Personality subtypes of young drivers: Relationship to risk-taking preferences, accident involvement, and response to a traffic safety campaign. *Transportation Research Part F: Traffic Psychology and Behaviour*, *4*(4), 279–297. doi:10.1016/S1369-8478(01)00029-8

Ulleberg, P., & Rundmo, T. (2003). Personality, attitudes and risk perception as predictors of risky driving behavior among young drivers. *Safety Science*, *41*(5), 427–443. doi:10.1016/S0925-7535(01)00077-7

Ullsperger, M., Harsay, H. A., Wessel, J. R., & Ridderinkhof, K. R. (2010). Conscious perception of errors and its relation to the anterior insula. *Brain Structure and Function*, *214*(5–6), 629–643. doi:10.1007/s00429-010-0261-1

Underwood, G. (2013). On-road behaviour of younger and older novices during the first six months of driving. *Accident Analysis and Prevention*, *58*, 235–243. doi:10.1016/j.aap.2012.03.019

Underwood, G., Chapman, P., Wright, S., & Crundall, D. (1999). Anger while driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *2*(1), 55–68. doi:10.1016/S1369-8478(99)00006-6

Underwood, G., Ngai, A., & Underwood, J. (2013). Driving experience and situation awareness in hazard detection. *Safety Science*, *56*, 29–35. doi:10.1016/j.ssci.2012.05.025

US Department of Health and Human Services (2008). *2008 physical activity guidelines for Americans*. Washington, DC: DHHS.

van Boxtel, J. J. A., Tsuchiya, N., & Koch, C. (2010). Consciousness and attention: On sufficiency and necessity. *Frontiers in Psychology*, *1*, 217. doi:10.3389/fpsyg.2010.00217

Van der Doef, M., & Maes, S. (1999). The job demand-control (-support) model and psychological well-being: A review of 20 years of empirical research. *Work & Stress*, *13*(2), 87–114. doi:10.1080/026783799296084

Van der Flier, H., & Schoonman, W. (1988). Railway signals passed at danger: Situational and personal factors underlying stop signal abuse. *Applied Ergonomics*, *19*(2), 135–141. doi:10.1016/0003-6870(88)90006-3

Van der Linden, D., Keijsers, G. P., Eling, P., & Van Schaijk, R. (2005). Work stress and attentional difficulties: an initial study on burnout and cognitive failures. *Work & Stress*, *19*(1), 23–36. doi:10.1080/02678370500065275

van Dongen, D., Claassen, L., Smid, T., & Timmermans, D. (2013). People's responses to risks of electromagnetic fields and trust in government policy: The role of perceived risk, benefits and control. *Journal of Risk Research*, *16*(8), 945–957. doi:10.1080/13669877.2012.761270

Van Knippenberg, D., & Sitkin, S. B. (2013). A critical assessment of charismatic—Transformational leadership research: Back to the drawing board? *The Academy of Management Annals*, *7*(1), 1–60. doi:10.1080/19416520.2013.759433

van Tol, J. (2015). Dutch Risk and Responsibility programme: Some research into citizens' views on a proportionate handling of risks and incidents. *Journal of Risk Research*. doi:10.1080/13669877.2014.910691

Van Wassenhove, W., Dressel, K., Perazzinin, A., & Ru, G. (2012). A comparative study of stakeholder risk perception and risk communication in Europe: A bovine spongiform encephalopathy case study. *Journal of Risk Research*, *15*(6), 565–582. doi:10.1080/13669877.2011.646290

van Winsen, F., de Mey, Y., Lauwers, L., Van Passel, S., Vancauteren, M., & Wauters, E. (2015). Determinants of risk behaviour: Effects of perceived risks and risk attitude on farmer's adoption of risk management strategies. *Journal of Risk Research*. doi:10.1080/13669877.2014.940597

Vangeli, P. A., Koutsidou, A., Gemitzi, A., & Tsagarakis, K. P. (2014). Public perception for monitoring and management of environmental risk: The case of the tires' fire in Drama region, Greece. *Journal of Risk Research*, *17*(9), 1183–1206. doi:10.1080/13669877.2013.875932

Vannan, C., & Gemmell, J. C. (2012). The role of regulators in reducing regulatory risk: Using scenario planning to assess the regulatory framework for carbon capture and storage. *Risk Management: A Journal of Risk, Crisis and Disaster, 14*(1), 27–41. doi:10.1057/rm.2011.11

Varonen, U., & Mattila, M. (2000). The safety climate and its relationship to safety practices, safety of the work environment and occupational accidents in eight wood–processing companies. *Accident Analysis and Prevention*, *32*(6), 761–769.

Vasey, M. W., Vilensky, M. R., Heath, J. H., Harbaugh, C. N., Buffington, A. G., & Fazio, R. H. (2012). It was as big as my head, I swear! Biased spider size estimation in spider phobia. *Journal of Anxiety Disorders*, *26*(1), 20–24. doi:10.1016/j.janxdis.2011.08.009

Vavrik, J. (1997). Personality and risk-taking: A brief report on adolescent male drivers. *Journal of Adolescence*, *20*(4), 461–465. doi:10.1006/jado.1997.0100

Vecchio, R. P. (1987). Situational leadership theory: An examination of a prescriptive theory. *Journal of Applied Psychology*, *72*(3), 444–451. doi:10.1037/0021-9010.72.3.444

Vecchio, R. P. (2003). *Organizational behavior: Core concepts* (5th ed.). Mason, OH: Thomson South Western.

Vecchio-Sadus, A. M., & Griffiths, S. (2004). Marketing strategies for enhancing safety culture. *Safety Science*, *42*(7), 601–619. doi:10.1016/j.ssci.2003.11.001

Villa, J. R., Howell, J. P., Dorfman, P. W., & Daniel, D. L. (2003). Problems with detecting moderators in leadership research using moderated multiple regression. *The Leadership Quarterly*, *14*(1), 3–23. doi:10.1016/S1048-9843(02)00184-4

Veldhuizen, M. G., Albrecht, J., Zelano, C., Boesveldt, S., Breslin, P., & Lundstrom, J. N. (2011). Identification of human gustatory cortex by activation likelihood estimation. *Human Brain Mapping*, *32*(12), 2256–2266. doi:10.1002/hbm.21188

Verplanken, B., Aarts, H., Van Knippenberg, A., & Van Knippenberg, C. (1994). Attitude versus general habit: Antecedents of travel mode choice. *Journal of Applied Social Psychology*, *24*(4), 285–300. doi:10.1111/j.1559-1816.1994.tb00583.x

Verwey, W. B., & Zaidel, D. M. (2000). Predicting drowsiness accidents from personal attributes, eye blinks and ongoing driving behaviour. *Personality and Individual Differences*, *28*(1), 123–142. doi:10.1016/S0191-8869(99)00089-6

Vinglis, E., Stoduto, G., Macartney-Filgate, M. S., Liban, C. B., & McLellan, B. A. (1994). Psychosocial characteristics of alcohol-involved and nonalcohol-involved seriously injured drivers. *Accident Analysis & Prevention*, *26*(2), 195–206. doi:10.1016/0001-4575(94)90089-2

Vinnem, J. E. (2015). Analysis of hydrocarbon leaks and verification as an operational barrier. *Journal of Risk Research*. doi:10.1080/13669877.2014.913661

Virtanen, M., Heikkilä, K., Jokela, M., Ferrie, J. E., Batty, G. D., Vahtera, J., & Kivimäki, M. (2012). Long working hours and coronary heart disease: A systematic review and meta-analysis. *American Journal of Epidemiology*, *176*(7), 586–596. doi:10.1093/aje/kws139

Visser, E., Pijl, Y. J., Stolk, R. P., Neeleman, J., & Rosmalen, J. G. M. (2007). Accident proneness, does it exist? A review and meta-analysis. *Accident Analysis & Prevention*, *39*(3), 556–564. doi:10.1016/j.aap.2006.09.012

Viswesvaran, C., Sanchez, J. I., & Fisher, J. (1999). The role of social support in the process of work stress: A meta-analysis. *Journal of Vocational Behavior*, *54*(2), 314–334. doi:10.1006/jvbe.1998.1661

Voigt, D. C., Dillard, J. P., Braddock, K. H., Anderson, J. W., Sopory, P., & Stephenson, M. T. (2009). Carver and White's 1994 BIS/BAS scales and their relationship to risky health behaviours. *Personality and Individual Differences*, *47*(2), 89–93. doi:10.1016/j.paid.2009.02.003

Volk, A. A., & Atkinson, J. A. (2013). Infant and child death in the human environment of evolutionary adaptation. *Evolution and Human Behavior*, *34*(3), 182–192. doi:10.1016/j.evolhumbehav.2012.11.007

Vom Hofe, A., Mainemarre, G., & Vannier, L. C. (1998). Sensitivity to everyday failures and cognitive inhibition: Are they related? *European Review of Applied Psychology*, 48(1), 49–56.

von Meyenfeldt, M. (2005). Cancer-associated malnutrition: An introduction. *European Journal of Oncology Nursing*, *9*(Supppl. 2), S35–S38. doi:10.1016/j.ejon.2005.09.001

Vroom, V. H., & Yetton, P. W. (1973). *Leadership and decision-making*. Pittsburgh, PA: University of Pittsburgh Press.

Vroomen, J., & de Gelder, B. (2004). Perceptual effects of cross-modal stimulation: Ventriloquism and the freezing phenomenon. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 141–150). Cambridge, MA: MIT Press.

Vul, E., Harris, C., Winkielman, P., & Pashler, H. (2009). Puzzlingly high correlations in fMRI studies of emotion, personality, and social cognition. *Perspectives on Psychological Science*, *4*(3), 274–290. doi:10.1111/j.1745-6924.2009.01125x

Wachtel, H., Beeman, D., & Pottenger, J. (1998). Human responses to weak EMF are biologically plausible because "ordinary" electrically excitable channels can account for an extreme sensitivity to electric fields in sharks and related species. *Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, *20*(6), 3272–3274.

Wada, N., Saito, O., Yamamotot, Y., Morioka, T., & Tokai, A. (2012). Evaluating effects on the flow of electrical and electronic equipment and energy consumption due to alternative consumption patterns in China. *Journal of Risk Research*, *15*(1), 107–130. doi:10.1080/13669877.2011.601322

Wadsworth, E. J. K., Simpson, S. A., Moss, S. C., & Smith, A. P. (2003). The Bristol stress and health study: Accidents, minor injuries and cognitive failures at work. *Occupational Medicine*, *53*(6), 392–397. doi:10.1093/occmed/kqg088

Wagenaar, W. (1992). Risk-taking and accident causation. In J. F. Yates (Ed.), *Risk-taking behavior* (pp. 257–281). Chichester, UK: Wiley.

Wagenaar, W. A., & Groeneweg, J. (1987). Accidents at sea: Multiple causes and impossible consequences. *International Journal of Man-Machine Studies*, *27*(5–6), 587–598. doi:10.1016/S0020-7373(87)80017-2

Wagner, A. D., Bunge, S. A., & Badre, D. (2004). Cognitive control, semantic memory, and priming: Contributions from prefrontal cortex. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 709–725). Cambridge, MA: MIT Press.

Wagstaff, A. S., & Lie, J. A. S. (2011). Shift and night work and long working hours: A systematic review of safety implications. *Scandinavian Journal of Work, Environment & Health*, *37*(3), 173–185. doi:10.5271/sjweh.3146

Walker, G. H., Stanton, N. A., & Chowdhury, I. (2013). Self explaining roads and situation awareness. *Safety Science*, *56*, 18–28. doi:10.1016/j.ssci.2012.06.018

Walker, G. H., Stanton, N. A., Kazi, T. A., Salmon, P. M., & Jenkins, D. P. (2009). Does advanced driver training improve situational awareness? *Applied Ergonomics*, *40*(4), 678–687. doi:10.1016/j.apergo.2008.06.002

Walker, G. H., Stanton, N. A., & Salmon, P. M. (2011). Cognitive compatibility of motorcyclists and car drivers. *Accident Analysis and Prevention*, *43*(3), 878–888. doi:10.1016/j.aap.2010.11.008

Walla, P., Richter, M., Färber, S., Leodolter, U., & Bauer, H. (2010). Food-evoked changes in humans: Startle response modulation and event-related brain potentials (ERPS). *Journal of Psychophysiology*, *24*(1), 25–32. doi:10.1027/0269-8803/a000003

Wallace, C., & Chen, G. (2006). A multilevel integration of personality, climate, self-regulation, and performance. *Personnel Psychology*, *59*(3), 529–557. doi:10.1111/j.1744-6570.2006.00046.x

Wallace, C. J., & Vodanovich, S. J. (2003a). Can accidents and industrial mishaps be predicted? Further investigation into the relationship between cognitive failure and reports of accidents. *Journal of Business and Psychology*, *17*(4), 503–514. doi:10.1023/A:1023452218225

Wallace, C. J., & Vodanovich, S. J. (2003b). Workplace safety performance: Conscientiousness, cognitive failure, and their interaction. *Journal of Occupational Health Psychology*, *8*(4), 316–327. doi:10.1037/1076-8998.8.4.316

Wallace, J. C., & Chen, G. (2005). Development and validation of a work-specific measure of cognitive failure: Implications for occupational safety. *Journal of Occupational and Organizational Psychology*, *78*(4), 615–632. doi:10.1348/096317905X37442

Wallace, J. C., Edwards, B. D., Arnold, T., Frazier, M. L., & Finch, D. M. (2009). Work stressors, role-based performance, and the moderating influence of organizational support. *Journal of Applied Psychology*, *94*(1), 254–262. doi:10.1037/a0013090

Wallace, J. C., Popp, E., & Mondore, S. (2006). Safety climate as a mediator between foundation climates and occupational accidents: A group-level investigation. *Journal of Applied Psychology*, *91*(3), 681–688. doi:10.1037/0021-9010.91.3.681

Wallace, M. T. (2004). The development of multisensory integration. In G. A. C. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 625–642). Cambridge, MA: MIT Press.

Wallace, M. T., & Stein, B. E. (2007). Early experience determines how the senses will interact. *Journal of Neurophysiology*, *97*(1), 921–926. doi:10.1152/jn.00497.2006

Walsh, G. W., Bartunek, J. M., & Lacey, C. A. (1998). A relational approach to empowerment. In C. L. Cooper & D. M. Rousseau (Eds.), *Trends in organizational behavior.* (Vol. 5, pp. 103–126). Chichester, UK: Wiley.

Walton, R. E. (1972). How to counter alienation in the plant. *Harvard Business Review*, *50*(6), 70–81.

Walumbwa, F. O., & Schaubroeck, J. (2009). Leader personality traits and employee voice behavior: Mediating roles of ethical leadership and work group psychological safety. *Journal of Applied Psychology*, *94*(5), 1275–1286. doi:10.1037/a0015848

Wang, R., Li, J-g., Fang, H-z., Tian, M-q., & Liu, J. (2012). Individual differences in holistic processing predict face recognition ability. *Psychological Science*, *23*(2), 169–177. doi:10.1177/0956797611420575

Wang, T., Moschandreas, D. J., Sattayatewa, C., Venkatesan, D., Noll, K. E., & Pagilla, K. R. (2013). A methodological approach for assessing indoor occupational risk from odor perception. *Journal of Risk Research*, *16*(1), 51–67, doi:10.1080/13669877.2012.725672

Wang, X-d., Zhang, J., Eberhart, D., Urban, R., Meda, K., Solorzano, C., … Basbaum, A. I. (2013). Excitatory superficial dorsal horn interneurons are functionally heterogeneous and required for the full behavioral expression of pain and itch. *Neuron*, *78*(2), 312–324. doi:10.1016/j.neuron.2013.03.001

Wang, X. S., Armstrong, M. E. G., Cairns, B. J., Key, T. J., & Travis, R. C. (2011). Shift work and chronic disease: The epidemiological evidence. *Occupational Medicine*, *61*(2), 78–89. doi:10.1093/occmed/kqr001

Ward, J. (2013). Synesthesia. *Annual Review of Psychology*, *64*, 49–75. doi:10.1146/annurev-psych-113011-143840

Ward, J., & Meijer, P. (2010). Visual experiences in the blind induced by an auditory sensory substitution device. *Consciousness and Cognition*, *19*(1), 492–500. doi:10.1016/j.concog.2009.10.006

Waring, A. (2013). *Corporate risk and governance: An end to mismanagement, tunnel vision and quackery*. Farnham, UK: Gower.

Waring, A. E. (1996). *Safety management systems*. London, UK: Chapman & Hall.

Waring, A. E., & Glendon, A. I. (1998). *Managing risk: Critical issues for survival and success into the 21st Century.* London, UK: Thomson International Business Press.

Warmelink, L., Vrij, A., Mann, S., Leal, S., Forrester, D., & Fisher, R. P. (2011). Thermal imaging as a lie detector tool at airports. *Law and Human Behaviour*, *35*(1), 40–48. doi:10.1007/s10979-010-9251-3

Watson, D., & Hubbard, B. (1996). Adaptational style and dispositional structure: Coping in the context of the Five-Factor model. *Journal of Personality*, *64*(4), 737–774. doi:10.1111/j.1467-6494.1996.tb00943.x

Watson, D., & Pennebaker, J. W. (1989). Health complaints, stress and distress: Exploring the central role of negative affectivity. *Psychological Review*, *96*(2), 324–354. doi:10.1037/0033-295X.96.2.234

Watson, G. W., Scott, D., Bishop, J., & Turnbeaugh, T. (2005). Dimensions of interpersonal relationships and safety in the steel industry. *Journal of Business and Psychology*, *19*(3), 303–318. doi:10.1007/s10869-004-2230-2

Weaver, C. S., Sloan, B. K., Brizendine, E. J., & Bock, H. (2006). An analysis of maximum vehicle G forces and brain injury in motorsports crashes. *Medicine and Science in Sports and Exercise*, *38*(2), 246–249. doi:10.1249/01.mss.0000184773.07870.5e

Webster, J. R., Beehr, T. A., & Christiansen, N. D. (2010). Toward a better understanding of the effects of hindrance and challenge stressors on work behavior. *Journal of Vocational Behavior*, *76*(1), 68–77. doi:10.1016/j.jvb.2009.06.012

Weick, K. E. (1987). Organization culture as a source of high reliability. *California Management Review*, *29*(2), 112–127.
Weick, K. E., & Roberts, K. H. (1993). Collective mind in organizations: Heedful interrelating on flight decks. *Administrative Science Quarterly*, *38*(3), 357–381.
Weick, K. E., & Sutcliffe, K. M. (2001). *Managing the unexpected: Assuring high performance in an age of complexity*. San Francisco, CA: Jossey-Bass.
Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (1999). Organizing for high reliability: Processes of collective mindfulness. In R. I. Sutton & B. M. Staw (Eds.), *Research in organizational behavior* (Vol. 21, pp. 81–123). Greenwich, CT: JAI Press.
Weingart, N. S., Wilson, R. M., Gibberd, R. W., & Harrison, B. (2000). Epidemiology of medical error. *British Medical Journal*, *320*(7237), 774–777. doi:10.1136/bmj.320.7237.774
Wen, W., Ishikawa, T., & Sato, T. (2011). Working memory in spatial knowledge acquisition: Differences in encoding processes and sense of direction. *Applied Cognitive Psychology*, *25*(4), 654–662. doi:10.1002/acp.1737
Werner. N. S., Schweitzer, N., Meindl, T., Duschek, S., Kambeitz, J., & Schandry, R. (2013). Interoceptive awareness moderates neural activity during decision-making. *Biological Psychology*, *94*(3), 498–506. doi:10.1016/j.biopsycho.2013.09.002
West, R. J., Elander, J., & French, D. (1991). *Decision making, personality and driving style as correlates of individual crash risk*. (TRRL Contractors Report No. 309). Crowthorne, UK: Transport and Road Research Laboratory.
West, R. J., Elander, J., & French, D. (1993). Mild social deviance, Type A behaviour pattern and decision-making style as predictors of self-reported driving style and traffic accident risk. *British Journal of Psychology*, *84*(2), 207–220. doi:10.1111/j.2044-8295.1993.tb02474.x
West, R. J., & Hall, J. (1997). The role of personality and attitudes in traffic accident risk. *Applied Psychology: An International Review*, *46*(3), 253–264. doi:10.1111/j.1464-0597.1997.tb01229.x
Westaby, J. D. & Lowe, J. K. (2005). Risk-taking orientation and injury among youth workers: Examining the social influence of supervisors, coworkers, and parents. *Journal of Applied Psychology*, *90*(5), 1027–1035. doi:10.1037/0021-9010.90.5.1027
Westerdahl, K. S. (2014). Societal consequences of radioactive releases in March 2011 in Japan and implications for the resilience concept. *Journal of Risk Research*, *17*(9), 1147–1160. doi:10.1080/13669877.2013.841732
Westoby, J. B., & Smith, J. M. (2000). *The 16PFS job spec*. Windsor, UK: Assessment and Selection in Employment (ASE).
Westrum, R., (1993). Cultures with requisite imagination. In: Wise, J., Stager, P., Hopkin, J. (Eds.), *Verification and Validation in Complex Man–Machine Systems*. New York, NY: Springer.
Westrum, R., (2004). A typology of organisational cultures. *Quality and Safety in Healthcare 13*(Suppl. II), ii22–ii27. doi:10.1136/qshc.2003.009522
Wheeler, D. S., Geis, G., Mack, E. H., LeMaster, T., & Patterson, M. D. (2013). High-reliability emergency response teams in the hospital: Improving quality and safety using in situ simulation training. *BMJ Quality & Safety*, *22*(6), 507–514. doi:10.1136/bmjqs-2012-000931
Whitener, E. M. (1997). The impact of human resource activities on employee trust. *Human Resource Management Review*, *7*(4), 389–404. doi:10.1016/S1053-4822(97)90026-7
Whitten, S. M., Hertzier, G., & Strunz, S. (2012). How real options and ecological resilience thinking can assist in environmental risk management. *Journal of Risk Research*, *15*(3), 331–346. doi:10.1080/13669877.2011.634525
Williams, F. M. K., Scollen, S., Cao, D-d., Memari, Y., Hyde, C. L., Zhang, B-h., … Spector, T. D. (2012). Genes contributing to pain sensitivity in the normal population: An exome sequencing study. *PLoS Genetics*, *8*(12), e1003095. doi:10.1371/journal.pgen.1003095
Williams, M. L., Podsakoff, P. W., Lodor, W. S., Huber, V. L., Howell, J. P., & Dorfman, P. W. (1988). A preliminary analysis of the construct validity of Kerr and Jermier's substitutes for leadership scales. *Journal of Occupational and Organizational Psychology*, *61*(4), 307–333. doi:10.1111/j.2044-8325.1988.tb00469.x
Williams, S., & Narendran, S. (1999). Determinants of managerial risk: Exploring personality and cultural influences. *Journal of Social Psychology*, *139*(1), 102–125. doi:10.1080/00224549909598365

Williamson, A. M., Feyer, A.-M., Cairns, D., & Biancotti, D. (1997). The development of a measure of safety climate: The role of safety perceptions and attitudes. *Safety Science*, *25*(1–3), 15–27.

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., … Duchaine, B. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences*, *107*(11), 5238–5241. doi:10.1073/pnas.0913053107

Wilson, R. S., Yu, I., & Bennett, D. A. (2011). Odor identification and mortality in old age. *Chemical Senses*, *36*(1), 63–67. doi:10.1093/chemse/bjq098

Wilson–Donnelly, K. A., Priest, H. A., Salas, E., & Burke, C. S. (2005). The impact of organizational practices on safety in manufacturing: A review and reappraisal. *Human Factors and Ergonomics in Manufacturing*, *15*(2), 135–176. doi:10.1002/hfm.20000

Winkler, D. (2013). Two paths of risk regulation: The concurrence of scientific and sociocultural decision-making in the European law of agricultural genetic engineering. *Journal of Risk Research*, *16*(7), 803–823. doi:10.1080/13669877.2012.737825

Winkler, M., Tuchs, K-D., Hughes, K., & Barclay, G. (2008). Theoretical and practical aspects of military wireless sensor networks. *Journal of Telecommunications and Information Technology*, *2*, 37–45.

Winkler, S. (2013). Characteristics of human vision. In R. Lukic (Ed.), *Perceptual digital imaging: Methods and applications* (pp. 1–35). Boca Raton, FL: CRC Press/Taylor & Francis.

Wintle, B. C., & Cleeland, B. (2012). Interpreting risk in international trade. *Journal of Risk Research*, *15*(3), 293–312. doi:10.1080/13669877.2011.646292

Wislar, J. S., Richman, J. A., Fendrich, M., & Flaherty, J. A. (2002). Sexual harassment, generalized workplace abuse and drinking outcomes: The role of personality vulnerability. *Journal of Drug Issues*, *32*(4), 1071–1088. doi:10.1177/002204260203200404

Witt, J. K., & Sugovic, M. (2013). Spiders appear to move faster than non-threatening objects regardless of one's ability to block them. *Acta Psychologica*, *143*(3), 284–291. doi:10.1016/j.actpsy.2013.04.011

Wittebaum, C. M., & Stasser, C. (1996). Management of information in small groups. In J. L. Nye & A. M. Brower (Eds.), *What's social about social cognition? Social cognition in small work groups.* Thousand Oaks, CA: Sage.

Wofford, J. C., & Liska, L. Z. (1993). Path–goal theories of leadership: A meta-analysis. *Journal of Management*, *19*(4), 857–876. doi:10.1177/014920639301900407

Wolfgang, A. P. (1988). Job stress in the health professions: A study of physicians, nurses, and pharmacists. *Hospital Topics*, *66*(4), 24–27. doi:10.1080/00185868.1988.10543616

Wong, C. M. L. (2015). Organisational risk perception and transformations in India's nuclear establishment. *Journal of Risk Research*, *18(8)*, 1012–1029. doi:10.1080/13669877.2014.910697

Wong, J. H. K., Kelloway, E. K., & Makhan, D. (2015). Safety Leadership. In S. Clarke, T. Probst, F. Guldenmund, & J. Passmore (Eds.), *The Wiley-Blackwell handbook of the psychology of occupational safety and workplace health*. Chichester, UK: Wiley-Blackwell.

Wood, S. W. M., & Bechara, A. (2014). The neuroscience of dual (and triple) systems in decision making. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 177–202). Washington, DC: American Psychological Association. doi:10.1037/14322-008

Woolf, S. H., & Aron, L. (Eds.). (2013). *U.S. health in international perspective: Shorter lives, poorer health*. Panel on Understanding Cross-National Health Differences among High-Income Countries. Committee on Population Division of Behavioral and Social Sciences and Education. Board on Population Health and Public Health Practice Institute of Medicine. National Research Council and Institute of Medicine. Washington, DC: National Academic Press.

World Economic Forum. (2014). *Global risks 2104: Insight report* (9th ed.). Geneva, Switzerland: World Economic Forum.

World Health Organization. (2008). *PRIMA-EF Guidance on the European framework for psychosocial risk management: Protecting workers' health* (series 9). Geneva, Switzerland: WHO.

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. Geneva, Switzerland: WHO.

World Health Organization. (2010). *Global status report on noncommunicable diseases*. Geneva, Switzerland: World Health Organization.

World Health Organization. (2011). *Global status report on non-communicable diseases 2010*. Geneva, Switzerland: WHO.

World Health Organization. (2013). *The top 10 causes of death*. Fact sheet N°310 (Updated July 2013). Geneva, Switzerland: WHO. (from http://who.int/.mediacentre/factsheets/fs310/en/)

World Meteorological Organization (WMO). (2013). *The global climate 2001–2010: A decade of climate extremes*. (WMO-No. 1103). Geneva, Switzerland: WMO.

Worrall, L., & Cooper, C. L. (1998). *Quality of working life 1998 survey of managers' changing experiences*. London, UK: Institute of Management.

Wrightsman, L. (1960). Effects of waiting for others on changes in level of felt anxiety. *Journal of Abnormal and Social Psychology*, *61*(2), 216–222. doi:10.1037/h0040144

Wu, T., Chang, S., Shu, C., Chen, C., & Wang, C. (2011). Safety leadership and safety performance in petrochemical industries: The mediating role of safety climate. *Journal of Loss Prevention in the Process Industries*, *24*(6), 716–721. doi:10.1016/j.jlp.2011.04.007

Wylie, R., Haraldsen, S., & Howe, J. M. (2015). A two-stage approach to defining an affected community based on the directly affected population and the sense of community. *Journal of Risk Research*. doi:10.1080/13669877.2014.961511

Wynne, R., & Rafferty, R. (1999). Ireland: Stress prevention in an airport management company. In M. Kompier & C. L. Cooper (Eds.), *Preventing stress, improving productivity: European case studies in the workplace* (pp. 242–263). London, UK: Routledge.

Xanthopoulou, D., Bakker, A. B., Demerouti, E., & Schaufeli, W. B. (2009). Reciprocal relationships between job resources, personal resources, and work engagement. *Journal of Vocational Behavior*, *74*(3), 235–244. doi:10.1016/j.jvb.2008.11.003

Yagil, D. & Luria, G. (2010) Friends in need: The protective effect of social relationships under low organizational safety climate. *Group and Organization Management*, *35*(6), 727–750. doi:10.1177/1059601110390936

Yan, J., & Brocksen, S. (2013). Adolescent risk perception, substance use, and educational attainment. *Journal of Risk Research*, *16*(8), 1037–1055. doi:10.1080/13669877.2013.788545

Yan, Q., Bligh, M. C., & Kohles, J. C. (2014). Absence makes the errors go longer: How leaders inhibit learning from errors. *Zeitschrift für Psychologie*, *222*(4), 233–245. doi:10.1027/2151-2604/a000190

Yang, S., Siechen, S., Sung, J., Chiba, A., & Saif, T. (2008). MEMS based sensors to explore the role of tension in axons for neuro-transmission. *Proceedings of the IEEE* (pp. 308–310). 978-1-4244-1793-3/08. Tucson, AZ, January 13–17.

Yang, T-H., Ku, C-Y., & Liu, M-N. (2015). An integrated system for information security management with the unified framework. *Journal of Risk Research*. doi:10.1080/13669877.2014.940593

Yang, Z. J., Seo, M., Rickard, L. N., & Harrison, T. M. (2015). Information sufficiency and attribution of responsibility: Predicting support for climate change policy and pro-environmental behaviour. *Journal of Risk Research*. doi:10.1080/13669877.2014.910692

Yaseen, S., Al-Habaibeh, A., Su, D., & Otham, F. (2013). Real-time crowd density mapping using a novel sensory fusion model of infrared and visual systems. *Safety Science*, *57*, 313–325. doi:10.1016/j.ssci.2013.03.007

Yasui, S. (2013). An analysis of the argument over the health effects of low-dose radiation exposure caused by the accident at the Fukushima Daiichi APP in Japan. *Journal of Risk Research*, *16*(8), 937–944. doi:10.1080/13669877.2013.788061

Ye, T., & Wang, M. (2013). Exploring risk attitude by a comparative experimental approach and its implication to disaster insurance practice in China. *Journal of Risk Research*, *16*(7), 861–878. doi: 10.1080/13669877.2012.743159

Yeomans, J. S., & Frankland, P. W. (1996). The acoustic startle reflex: Neurons and connections. *Brain Research Reviews*, *21*(3), 301–314. doi:10.1016/0165-0173(96)00004-5

Young, D. L., Goodie, A. S., Hall, D. B., & Wu, E. (2012). Decision making under time pressure, modeled in a prospect theory framework. *Organizational Behavior and Human Decision Processes*, *118*(2), 179–188. doi:10.1016/j.obhdp.2012.03.005

Young, K. L., & Salmon, P. M. (2012). Examining the relationship between driver distraction and driving errors: A discussion of theory, studies, and methods. *Safety Science*, *50*(2), 165–174. doi:10.1016/j.ssci.2011.07.008

Young, K. L., Salmon, P. M., & Cornelissen, M. (2013a). Distraction-induced driving error: An examination of the errors made by distracted and undistracted drivers. *Accident Analysis and Prevention*, *58*, 218–225. doi:10.1016/j.aap.2012.06.001

Young, K. L., Salmon, P. M., & Cornelissen, M. (2013b). Missing links? The effects of distraction on driver situation awareness. *Safety Science*, *56*, 36–43. doi:10.1016/j.ssci.2012.11.004

Yoshimoto, S., Kuroda, Y., Imura, M., & Oshiro, O. (2012). Superimposed skin pressure sensor. *SIGGRAPH Asia 2012*, Singapore, Nov 28–Dec 1.

Yost, W. A. (2004). Determining an auditory scene. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 385–396). Cambridge, MA: MIT Press.

Youle, A. (2005). The thermal environment. In K. Gardiner & J. M. Harrington (Eds.), *Occupational hygiene* (3rd ed., pp. 286–306). Oxford, UK: Blackwell.

Yu, J., & Williford, W. R. (1993). Alcohol and risk/sensation seeking: Specifying a causal model on high-risk driving. *Journal of Addictive Diseases*, *12*(1), 79–96. doi:10.1300/J069v12n01_07

Yuan, Z., Li, Y., & Lin, J. (2014). Linking challenge and hindrance stress to safety performance: The moderating effect of core self-evaluation. *Personality and Individual Differences*, *68*, 154–159. doi:10.1016/j.paid.2014.04.025

Yuen, K. S., & Lee, T. (2003). Could mood state affect risk-taking decisions? *Journal of Affective Disorders*, *75*(1), 11–18. doi:10.1016/S0165-0327(02)00022-8

Yukl, G. A. (1998). *Leadership in organizations.* Englewood Cliffs, NJ: Prentice Hall.

Yule, S. (2002). *Do transformational leaders lead safer businesses?* Paper presented at the 25th International Congress of Applied Psychology, Singapore, July.

Zaccaro, S. J., & Marks, M. A. (1999). The role of leaders in high–performance teams. In E. Sundstrom, B. Schneider, C. Crocker et al. (Eds.), *Supporting work team effectiveness.* (pp. 95–125). San Francisco, CA: Jossey–Bass.

Zacharatos, A., Barling, J., & Iverson, R. D. (2005). High-performance work systems and occupational safety. *Journal of Applied Psychology*, *90*(1), 77–93. doi:10.1037/0021-9010.90.1.77

Zaidel, D. M. (1992). A modelling perspective on the culture of driving. *Accident Analysis & Prevention*, *24*(6), 585–597. doi:10.1016/0001-4575(92)90011-7

Zaréa, M., Pognonec, G., Schmidt, C., Schnur, T., Lana, J., Boehm, C., … Rigaud, E. (2013). First steps in developing an automated aerial surveillance approach. *Journal of Risk Research*, *16*(3–4), 407–420. doi:10.1080/13669877.2012.729520

Zayas, V., Mischel, W., & Pandey, G. (2014). Mind and brain in delay of gratification. In V. F. Reyna & V. Zayas (Eds.), *The neuroscience of risky decision making* (pp. 145–176). Washington, DC: American Psychological Association. doi:10.1037/14322-007

Zeelenberg, M., van Dijk, W. W., Manstead, A. S. R., & van de Pligt, J. (2000). On bad decisions and disconfirmed expectancies: The psychology of regret and disappointment. *Cognition & Emotion*, *14*(4), 521–541. doi:10.1080/026999300402781

Zelek, J., Bromley, S., Asmar, D., & Thompson, D. (2003). A haptic glove as a tactile-vision sensory substitution for wayfinding. *Journal of Visual Impairment & Blindness*, *97*(10), 621–632.

Zhang, L., He, G-z., Mol, A. P. J., & Lu, Y-l., (2013). Public perceptions of environmental risk in China. *Journal of Risk Research*, *16*(2), 195–209. doi:10.1080/13669877.2012.726240

Zhou, W., Jiang, Y., He, S., & Chen, D. (2010). Olfaction modulates visual perception in binocular rivalry. *Current Biology*, *20*(15), 1356–1358. doi:10.1016/j.cub.2010.05.059

Zhu, D-q., Xie, X-f., & Xie, J-q. (2012). When do people feel more risk? The effect of ambiguity tolerance and message source on purchasing intention of earthquake insurance. *Journal of Risk Research*, *15*(8), 951–965. doi:10.1080/13669877.2012.686051

Zingg, A., Cousin, M-E., Connor, M., & Siegrist, M. (2013). Public risk perception in the total meat supply chain. *Journal of Risk Research*, *16*(8), 1005–1020. doi:10.1080/13669877.2013.788057

Zingg, A., & Siegrist, M. (2012). Lay people's and experts' risk perception and acceptance of vaccination and culling strategies to fight animal epidemics. *Journal of Risk Research*, *15*(1), 53–66. doi:10.1080/13669877.2011.601321

Zohar, D. (1980). Safety climate in industrial organizations: Theoretical and applied implications. *Journal of Applied Psychology*, *65*(1), 96–102. doi:10.1037/0021-9010.65.1.96

Zohar, D. (2000). A group-level model of safety climate: Testing the effect of group climate on microaccidents in manufacturing jobs. *Journal of Applied Psychology*, *85*(4), 587–596. doi:10.1037/0021-9010.85.4.587

Zohar, D. (2002a). Modifying supervisory practices to improve sub-unit safety: A leadership-based intervention model. *Journal of Applied Psychology*, *87*(1), 156–163. doi:10.1037/0021-9010.87.1.156

Zohar, D. (2002b). The effects of leadership dimensions, safety climate, and assigned priorities on minor injuries in work groups. *Journal of Organizational Behavior*, *23*(1), 75–92. doi:10.1002/job.130

Zohar, D. (2003). The influence of leadership and climate on occupational health and safety. In D. A. Hofmann & L. E. Tetrick (Eds.), *Health and safety in organizations* (pp. 201–230). San Francisco, CA: Jossey-Bass.

Zohar, D. (2008). Safety climate and beyond: A multi-level multi-climate framework. *Safety Science*, *46*(3), 376–387. doi:10.1016/j.ssci.2007.03.006

Zohar, D. (2010). Thirty years of safety climate research: Reflections and future directions. *Accident Analysis and Prevention*, *42*(5), 1517–1522. doi:10.1016/j.aap.2009.12.019

Zohar, D., Huang, Y., Lee, J., & Robertson, M. (2014). A mediation model linking dispatcher leadership and work ownership with safety climate as predictors of truck driver safety performance. *Accident Analysis and Prevention*, *62*, 17–25. doi:10.1016/j.aap.2013.09.005

Zohar, D., Livne, Y., Tenne-Gazit, O., Admi, H., & Donchin, Y. (2007). Healthcare climate: A framework for measuring and improving patient safety. *Critical Care Medicine*, *35*(5), 1312–1317. doi:10.1097/01.CCM.0000262404.10203.C9

Zohar, D., & Luria, G. (2003). The use of supervisory practices as leverage to improve safety behavior: A cross-level intervention model. *Journal of Safety Research*, *34*(5), 567–577. doi:10.1016/j.jsr.2003.05.006

Zohar, D., & Luria, G. (2004). Climate as a social-cognitive construction of supervisory practices: Scripts as proxy of behavior patterns. *Journal of Applied Psychology*, *89*(2), 322–333. doi:10.1037/0021-9010.89.2.322

Zohar, D., & Luria, G. (2005). A multilevel model of safety climate: Cross-level relationships between organization and group-level climates. *Journal of Applied Psychology*, *90*(4), 616–628. doi:10.1037/0021-9010.90.4.616.

Zohar, D., & Luria, G. (2010). Group Leaders as Gatekeepers: Testing Safety Climate Variations across Levels of Analysis. *Applied Psychology*, *59*(4), 647–673. doi:10.1111/j.1464-0597.2010.00421.x

Zohar, D., & Polachek, T. (2014). Discourse-based intervention for modifying supervisory communication as leverage for safety climate and performance improvement: A randomized field study. *Journal of Applied Psychology*, *99*(1), 113–124. doi:10.1037/a0034096

Zohar, D., & Tenne-Gazit, O. (2008). Transformational leadership and group interaction as climate antecedents: A social network analysis. *Journal of Applied Psychology*, *93*(4), 744–757. doi:10.1037/0021-9010.93.4.744

Zuckerman, M. (1979a). *Sensation seeking: Beyond the optimal level of arousal*. Hillsdale, NJ: Erlbaum.

Zuckerman, M. (1979b). Sensation seeking and risk taking: Emotional distress and behavioral problems. *Adolescence*, *30*, 757–777.

Zuckerman, M. (Ed.). (1983). *Biological bases of sensation seeking, impulsivity, and anxiety*. Hillsdale, NJ: Erlbaum.

Zuckerman, M. (1990). The psychophysiology of sensation seeking. *Journal of Personality*, *58*(1), 313–345. doi:10.1111/j.1467-6494.1990.tb00918.x

Zuckerman, M. (1994). *Behavioural expressions and biosocial bases of sensation seeking.* Cambridge, UK: University of Cambridge Press Syndicate.

Zuckerman, M. (2004). *Behavioral expressions and biosocial bases of sensation seeking.* Cambridge, UK: Cambridge University Press.

Zuckerman, M., & Neeb, M. (1980). Demographic influences in sensation seeking and expression of sensation seeking in religion, smoking and driving habits. *Personality and Individual Differences*, *1*(3), 197–206. doi:10.1016/0191-8869(80)90051-3

Zwerling, C. (1993). Current practice and experience in drug and alcohol testing. *Bulletin on Narcotics*, *45*(2), 155–196.

Glossary

Generally, a term is provided in full in its first occurrence with the acronym in parentheses in each chapter. In the few instances in which the same acronym represents more than one expanded term, context should provide guidance on which term is referred to. Where an acronym is in frequent common use, its expanded description appears only in the Glossary.

2D	Two-dimensional
3D	Three-dimensional
16PF	16 personality factor scales (questionnaire)
AA	American Airlines
AC	Alternating current
ACAS	Aircraft collision avoidance system (aircraft hazard warning system)
ACC	Anterior cingulate cortex (brain region)
ACTH	Adrenocorticotropic hormone
AI	Anterior insula (brain region)
AIDS	Acquired immune deficiency syndrome
AIM	Affect infusion model
ALARA	As low as reasonably acceptable (RM standard)
ALARP	As low as reasonably practicable (RM standard)
ANT	Actor-network theory
AR	Augmented reality
AT	Ambiguity tolerance (ID)
ATC	Air traffic control
ATSB	Australian Transport Safety Bureau
AVP	Aasopressin (hormone)
BART	Balloon Analogue Risk Task (measure of R-T behavior under ambiguity)
BAS	Behavior approach system (appetitive motivation)
BCM	Business continuity management (RM technique)
BIS	Behavior inhibition system (negative reactivity)
BIT	Bilateral investment treaty
BMI	Body Mass Index
BPA	Anti-Bisphenol A
bps	Bits per second
BSE	Bovine spongiform encephalopathy
BSI	British Standards Institute
Bt	*Bacillus thuringiensis*
°C	Degrees Centigrade
CA	Condition awareness

CASA	Civil Aviation Safety Authority (Australia)
CAT	Computed axial tomography (scan technique)
CBT	Cognitive behavior therapy
CC	Climate change
CCK	Cholecystokinin
CCTV	Closed circuit television
CDRM	Company dynamic response map (RM technique)
CEO	Chief executive officer
CERC	Crisis and emergency risk communication (RM technique)
CFQ	Cognitive Failures Questionnaire
CH_4	Methane
CI	Collaboration Index
CM	Crisis management
CN	Central nucleus (amygdala)
CNS	Central nervous system *or* Convention on Nuclear Safety (1994)
CNV	Fifth cranial nerve (trigeminal)
CO	Carbon monoxide
CO_2	Carbon dioxide
COR	Conservation of resources (stress model)
CR	Cognitive reappraisal
CRM	Crew resource management
CRO	Chief risk officer
CS	Conditioned stimulus
CSE	Core self-evaluation
CSS	Civil security system
CT	Computed tomography (scan technique)
CVD	Cardiovascular disease
CWBs	Counterproductive work behaviors
CWM	Conservative white male (RP effect)
dACC	Dorsal anterior cingulate cortex (brain region)
dAI	Dorsal anterior insula (brain region)
DARPA	Defense Advanced Research Projects Agency (United States)
dB	Decibel
DC	Direct current *or* demands-control (stress model)
DCS	Demands-control-support (stress model)
DEFRA	Department of the Environment, Farming and Rural Affairs (United Kingdom)
DHHS	Department of Health and Human Services (United States)
DLPFC	Dorsolateral prefrontal cortex (brain region)
DM	Decision making
DMN	Default mode network (distributed brain region)
DMPFC	Dorsomedial prefrontal cortex (brain region)
DNA	Deoxyribonucleic acid
doi	Digital object identifier
DROP	Disaster resilience of place
DTI	Diffusion tensor imaging (scan technique)
DVC	Dorsal vagal complex (brain region)
EAP	Employee assistance program
ECAM	Electronic centralized aircraft monitor (aircraft hazard warning system)
ECG	Electrocardiogram (scan technique)

Ed	Editor
edn	Edition
EEG	Electroencephalography (scan technique)
EGS	Enhanced geothermal (power) systems
EI	Emotional intelligence (ID)
EICAS	Engine indicating and crew alerting system (aircraft hazard warning system)
EID	Emerging infectious disease
ELF	Extra low frequency
EMT	Error management theory
ENS	Enteric nervous system
EP	Evolutionary psychology
EPPM	Extended parallel processing model (a social cognitive theory: Witte)
ER	Emotion regulation
ERA	Environmental risk assessment (RM technique)
ERM	Enterprise risk management *or* environmental risk management
ERMF	Emerging risk management framework
ERN	Error related negativity (EEG neural response)
ERP	Event-related potential (EEG neural response)
ERRA	Emerging risks representative industrial application (RM technique)
ES	Expressive suppression
ETA	Event tree analysis (RM technique)
EU	European Union
EUT	Expected utility theory
FAA	Federal Aviation Administration (United States)
FAE	Fundamental attributional error
FASA	Factors affecting situation awareness
FDA	Federal Drug Administration (United States)
FfG	Fusiform gyrus (brain feature)
FFM	Five-factor (personality) model
FMEA	Failure modes and effects analysis (RM technique)
fMRI	Functional magnetic resonance imaging (scan technique)
fNIRS	Functional near-infrared spectroscopy (scan technique)
FoF	Fight or flight (threat response)
FOT	Future orientation (ID)
FSA	Food Standards Agency (United Kingdom)
FTA	Fault tree analysis (RM technique)
FTT	Fuzzy trace theory
G/g	Gravity
GET	Global energy transition (model)
GHQ	General Health Questionnaire
gHz	Gigahertz
GI	Gastrointestinal (tract)
GIS	Geographic information system *or* gastrointestinal system
GM	Genetically modified
GMO	Genetically modified organism
GNP	Gross national product
GPS	Global positioning system
GPWS	Ground proximity warning system (aircraft hazard warning system)
HAPA	Health action process approach (a social cognitive theory)

HAZID	Hazard identification (RM technique)
HAZOP	Hazard and operability study (RM technique)
HBM	Health belief model (a social cognitive theory)
HCR-20	Historical, Clinical, and Risk Management (scale)
HE	Human error
HEFCE	Higher Education Funding Council for England
HF	Human factors
Hg	Mercury
HIV	Human immunosuppressive virus
HPAI	Highly pathogenic avian influenza
HR	Human resource/s
HRA	Human reliability assessment (RM technique)
HRO	High reliability organization
HSC	Health & Safety Commission (United Kingdom)
HS&E	Health, safety and environment
H&S	Health and safety
HSS	Human sensory system
HVDC	High-voltage direct current
Hz	Hertz (cycles per second)
IA	Impact assessment *or* interoceptive awareness
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
ICT	Information communications and technology
ID	Individual difference
IEEE	Institute of Electrical and Electronics Engineers
IFG	Inferior frontal gyrus (brain feature)
IFS	Inferior frontal sulcus (brain feature)
IGT	Iowa Gambling Task (DM under ambiguity rather than risk)
ILO	International Labor Organization
iNTeg-Risk	Integrated management of emerging, new technology related risks
IoT	Internet of Things
IPL	Inferior parietal lobe (brain region)
IPS	Intraparietal sulcus (brain feature)
IQ	Intelligence quotient
IR	Infrared
IRGC	International Risk Governance Council
ISI	Institute for Scientific Information
ISISM	Integrated system for information security management
ISO	International Organization for Standardization
IT	Information technology
ITS	Integrated testing strategy (RM technique)
JDR	Job demands–job resources (stress model)
JRR	*Journal of Risk Research*
KCS	Korean Customs Service
km	Kilometer
kHz	Kilohertz
kph	Kilometers per hour
KPI	Key performance indicator
LAN	Local area network

LC	Locus coeruleus (brain feature)
LCA	Lifecycle assessment (RM technique)
LED	Light-emitting diode
LGN	Lateral geniculate nucleus (brain feature—thalamus)
lidar	Light detection and ranging
LMN	Lower motor neuron (brain feature)
LMX	Leader–member exchange (theory)
LN	Lateral nucleus (amygdala)
LoC	Locus of control (ID)
LOC	Loss of control (aviation accident type)
LPFC	Lateral prefrontal cortex (brain region)
LTM	Long-term memory
m	Million *or* meters
MAFF	Ministry of Agriculture, Fisheries, and Food (United Kingdom)
MBEA	Management-by-exception active
MBEP	Management-by-exception passive
MCC	Midcingulate cortex (brain region)
MDZ	Medial defense zone (brain region)
MEG	Magnetoencephalography (scan technique)
MEMS	Microelectromechanical systems
MEOW	Maximum envelope of water (in storm surge or flood)
MF	Magnetic field
MHz	Megahertz
MI	Multisensory integration
min	Minute
MIT	Massachusetts Institute of Technology
MLQ	Multifactor Leadership Questionnaire
MMH	Mood maintenance hypothesis
MNS	Mirror neuron system (distributed brain network)
MOFC	Medial orbitofrontal cortex (brain region)
MPFC	Medial prefrontal cortex (brain region)
MR	Mixed reality
MRI	Magnetic resonance imaging (scan technique)
MRM	Modern risk management
MRT	Mean radiant temperature
ms	Milliseconds
m/s	Meters per second
MSAW	Minimum safe altitude warning (aircraft hazard warning system)
MSV	Message sensation value
MT	Middle temporal (brain region)
MTG	Middle temporal gyrus (brain feature)
NA	Nucleus accumbens (brain feature) *or* negative affectivity
NASA	National Aeronautics and Space Administration (United States)
Na-tech	Natural-technological (hazards)
NB	*nota bene*
NCD	Noncommunicable disease
NEO-PI	Neuroticism Extraversion Openness Personality Inventory
NHS	National Health Service (United Kingdom)
NIMBY	Not in my backyard

nm	Nanometer
NPV	Net present value
NRC	Nuclear Regulatory Commission (United States)
NST	Nucleus of the solitary tract (brainstem feature)
NTSB	National Transportation Safety Board (United States)
NSW	New South Wales
OCBs	Organizational citizenship behaviors
OCD	Obsessive compulsive disorder
OECD	Organization for Economic Development and Cooperation
OEL	Occupational exposure limit
OFC	Orbitofrontal cortex (brain region)
OIE	World Organization for Animal Health
OIM	Offshore installation manager
OPQ	Occupational Personality Questionnaire
OR	Orienting response/reflex/reaction (threat response)
OSHA	Occupational Safety and Health Administration (United States)
PA	Positive affectivity
PAG	Periaqueductal gray (brain feature)
PCA	Principal components analysis (statistical technique)
PCC	Posterior cingulate cortex (brain region)
PDA	Personal digital assistant
PE	Person–environment (fit)
PES	Posterror slowing (EEG neural response)
PET	Positron emission tomography (scan technique)
PFC	Prefrontal cortex (brain region)
pFMC	Posterior frontomedial cortex (brain region)
PF-MF	Power-frequency magnetic field
PLoS	Public Library of Science
PMC	Premotor cortex (brain region)
PMT	Protection motivation theory (a social cognitive theory)
PNE	Peaceful nuclear explosion
PNS	Peripheral nervous system
pp	Pages
PP	Precautionary principle (RM technique)
PPC	Posterior parietal cortex (brain region)
PPE	Personal protective equipment
ppm	Parts per million
PPP	Public–private partnership
Pt	Platinum
PT	Prospect theory
PTSD	Posttraumatic stress disorder
PZM	Pressure zone microphone
QRA	Quantitative risk assessment (RM technique)
R&D	Research and development
RA	Risk assessment/appraisal (RM technique)
rACC	Right anterior cingulate cortex (brain region)
RAFH	Risk-as-feelings hypothesis
RAMCAP	Risk analysis and management for critical asset protection (RM technique)
RBM	Risk breakdown matrix (RM technique)

RBS	Risk breakdown structure (RM technique)
RC	Risk communication
RCZ	Rostral cingulate zone (brain region)
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals (EU)
RET	Rational emotional therapy
RFID	Radio frequency identification
RG	Risk governance
RIMCAS	Runway incursion monitoring and collision avoidance system (aircraft hazard warning system)
RISP	Risk information seeking and processing (model)
RM	Risk management
RP	Risk perception
RR	Risk regulation
RST	Reinforcement sensitivity theory
RT	Reaction/response time
R-T	Risk taking
rTMS	Repetitive transcranial magnetic stimulation (scan technique)
s	Second/s
SA	Situation awareness
SAA	Sense–assess–augment (neuroergonomics framework)
SARF	Social amplification/attenuation of risk framework
SARS	Severe acute respiratory syndrome
SBA	Safety barrier analysis (RM technique)
SBV	Schmallenberg virus
SC	Superior colliculus (brainstem feature)
SCN	Suprachiasmatic nucleus (hypothalamus feature)
SCORM	Supply chain operations reference model
SCRM	Supply chain risk management
Se	Selenium
SE	Southeast
SED	Sensory enhancement device
SEM	Structural equation model (ing) (statistical analysis technique)
SI	Primary somatosensory cortex (brain region)
SII	Secondary somatosensory cortex (brain region)
SIPM	Social information processing model
SLOSH	Sea, lake, and overland surge from hurricanes (model)
SMA	Supplementary motor area (brain region)
SMEs	Small and medium-sized enterprises
SMG	Supramarginal gyrus (brain feature)
sMRI	Structural magnetic resonance imaging (scan technique)
SMS	Safety management system
SNS	Sympathetic nervous system
SoD	Sense of direction (ID)
SOES	Spatial orientation enhancement system
SoVI	Social vulnerability index
SPAM	Situation Present Assessment Method
SPECT	Single proton emission computed tomography (scan technique)
SRM	Social risk management
SS	Sensation seeking/seeker (ID)

SSD	Sensory substitution device
SSS	Sensation Seeking Scale (Zuckerman)
STAI	State-Trait Anxiety Inventory
STCA	Short-term conflict alert (aircraft hazard warning system)
STEL	Short-term exposure limit
STS	Superior temporal sulcus (brain feature)
TABP	Type A behavior pattern
TAT	Thematic Appreciation Test
TAWS	Terrain awareness warning system (aircraft hazard warning system)
TBI	Traumatic brain injury
TCAS	Traffic collision avoidance system (aircraft hazard warning system)
tDCS	Transcranial direct current stimulation (scan technique)
TI	Tonic immobility (threat response)
TMI	Three Mile Island (United States)
ToM	Theory of mind
TPB	Theory of planned behavior (a social cognitive theory)
TPJ	Temporoparietal junction (brain region)
TRA	Theory of reasoned action (a social cognitive theory)
TSAS	Tactical situational awareness system
TSC	Total safety culture
TSE	Time's subjective expansion
UCS	Unconditioned stimulus
UK	United Kingdom
ULF	Ultralow frequency
μm	Micrometer
U.S.	United States
UV	Ultraviolet
UAS	Unmanned aircraft system
v	Volt
vAI	Ventral anterior insula (brain region)
VBM	Voxel-based morphometry (scan technique)
VMPFC	Ventromedial prefrontal cortex (brain region)
VOR	Vestibuloocular reflex
VPFC	Ventral prefrontal cortex (brain region)
VR	Virtual reality
vs.	Versus
VS	Ventral striatum (brain region)
VVC	Ventral vagal complex (brain region)
WBGT	Wet bulb globe temperature
WEF	World Economic Forum
WHO	World Health Organization
WHP	Work health promotion
WM	Working memory
WMO	World Meteorological Organization
w-o-m	Word of mouth
WSA	Work safety awareness (model)
WTO	World Trade Organization
WTP	Willingness to pay

Index

D

E

F