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Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework

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Introduction

The following literature review addresses the effects of various stressors on cognition. While attempting to be as inclusive as possible, the review focuses its examination on the relationships between cognitive appraisal, attention, memory, and stress as they relate to information processing and human performance. The review begins with an overview of constructs and theoretical perspectives followed by an examination of effects across attention, memory, perceptual-motor functions, judgment and decision making, putative stressors such as workload, thermals, noise, and fatigue and closes with a discussion of moderating variables and related topics. In summation of the review, a conceptual framework for cognitive process under stress has been assembled. As one might imagine, the research literature that addresses stress, theories governing its effects on human performance, and experimental evidence that supports these notions is large and diverse. In attempting to organize and synthesize this body of work, I was guided by several earlier efforts (Bourne & Yaroush, 2003; Driskell, Mullen, Johnson, Hughes, & Batchelor, 1992; Driskell & Salas, 1996; Handcock & Desmond, 2001; Stokes & Kite, 1994). These authors should be credited with accomplishing the monumental task of providing focused reviews in this area and their collective efforts laid the foundation for this present review. Similarly, the format of this review has been designed in accordance with these previous exemplars. However, each of these previous efforts either simply reported general findings, without sufficient experimental illustration, or narrowed their scope of investigation to the extent that the breadth of such findings remained hidden from the reader. Moreover, none of these examinations yielded an architecture that adequately describes or explains the inter-relations between information processing elements under stress conditions. It is the author's hope that this review may provide an initial step toward this end.

What is Stress?

It's a question that has beguiled many prominent researchers of this era. The term itself is amorphous and sustains the difficulty in discerning its meaning. Definitions of stress range from metallurgical strain to one's emotional wits end. Although convergence on a common definition of stress is highly desirable, the scientific community has not been able to do so. Instead, the research literature reflects wide and divergent opinions concerning stress.

Stokes and Kite (2001) suggest that the term's versatility (its range of application), is its undoing as a useful scientific term or concept, and they are not alone in this assertion (Tepas & Price, 2001). Accordingly, stress can be viewed as, "…an agent, circumstance, situation, or variable that disturbs the 'normal' functioning of the individual…stress [is also] seen as an effect—that is the disturbed state itself…this bifurcation of meaning is arguably the most fundamental source of the confusion surrounding the stress concept." (p. 109). Stokes and Kite contend that there are no psychological stressors in any absolute, objective sense.

In their review of the construct and its evolution, they assert that there are two traditional models of psychological stress, stimulus-based and response-based. The stimulus-based stress approach assumes certain conditions to be stressful and dubs these stressors (i.e., workload, heat and cold, time pressure, etc.). Historically this has resulted in researchers selecting such exogenous variables, applying them experimentally, and concluding that the outcome witnessed was likely the result of a "stress" manipulation. The approach is based on an engineering analogy (mechanical stress and emotional strain) that Stokes and Kite contend is inadequate. They argue that this model ignores individual differences, does not evaluate circumstances, and leaves out emotion—we are not just machines that react to environmental stimuli.

The response-based stress approach holds that stress is defined by the pattern of responses (i.e., behavioral, cognitive, and affective) that result from exposure to a given stressor. In contrast to the stimulus-based approach, these variables can be considered endogenous or coming from within the individual. This model has relied heavily on the work of Yerkes and Dodson (1908) and later Selye (1956) and found its emphasis in physiological dimensions (this evolution is described in more detail in the following section).

Stokes and Kite (2001) suggested that physiological measures have failed to provide a complete understanding of the human stress response and do not necessarily equate to psychological stress, and thus a third approach to understanding the human stress response has emerged—the transactional model. Transactional models view stress as the interaction between the environment and individual, emphasizing the role of the individual's appraisal of situations in shaping their responses. From the transactional approach, stress is defined as, "…the result of a mismatch between individuals' perceptions of the demands of the task or situation and their perceptions of the resources for coping with them." (p. 116). The fundamental assumptions underlying this approach are discussed in greater detail during a review of the cognitive appraisal literature.

There seem to be as many definitions of stress as there are stress researchers. Adding to the difficulty in finding an adequate definition for stress is the fact that the term is used in association with so many different constructs. For instance, Tepas and Price (2001) suggested that stress is commonly connected to the following concepts: adaptation, anxiety, arousal, burnout, coping, exertion, exhaustion, exposure, fatigue, hardiness, mental load, repetitiveness, strain, stressor, and tension. Given the formidable breadth of the domain it is not difficult to see why stress as a construct has become unwieldy for most researchers.

For the sake of simplicity and coherence, I have selected a definition proposed by McGrath (1976) that seems to be broad enough to incorporate most of the current assumptions about what stress is and is not, yet focused enough to be meaningful. McGrath conceptualized stress as the interaction between three elements: perceived demand, perceived ability to cope, and the perception of the importance of being able to cope with the demand. Unlike many previous definitions of stress, this formulation distinctly incorporates the transactional process believed to be central to current cognitive appraisal theories. No longer is stress seen merely as a mismatch between demand and ability; on the contrary, one's perception of these two elements, and more importantly the desire or motivation one experiences to meet the demand, is central to the construct.

While McGrath's (1976) definition of stress provides a high-level concept of stress, it says little if anything about how stress affects human performance. To do so requires a theory of underlying mechanisms. Unfortunately, no unitary framework has gained consensus by the scientific community. Instead, several theories have been proposed and debated.

Theoretical Perspectives

Arousal, Activation, and Energetical Theories

Yerkes-Dodson and Arousal Theory

One of the earliest theories that attempted to provide a comprehensive framework was arousal theory. Razmjou (1996) provided us with a definition for arousal that seems to encompass most perspectives:

"Arousal is a hypothetical construct that represents the level of central nervous system activity along a behavioral continuum ranging from sleep to alertness." (p. 530). Stokes and Kite (2001) have also suggested that arousal be considered, "the basic energetic state of an organism." (p. 113). Combined, these definitions provide an adequate foundation for understanding the rather general and nonspecific nature of arousal as it is typically discussed in the research literature. As this theory states, arousal mobilizes and regulates the human stress response. Everyday living informs us that various events and conditions elicit a response. This response frequently incorporates physiological, cognitive, behavioral, and emotional dimensions. As arousal theory would assert, what facilitates this response is an energetical or activation system that is general and nonspecific. Although the arousal response is multidimensional, historically, physiological markers have dominated its measurement.

To understand how the scientific community first came to support arousal theory we must go back to the turn of the twentieth century, specifically to the work of Yerkes and Dodson (1908). Yerkes and Dodson examined mice involved in a simple learning task. The task put before the mice was to learn to discern a white from a black doorway and pathway (and to refrain from walking down the black pathway). Thus performance was measured by how many attempts the mice made prior to learning that exploring the dark pathway was not a good idea. Electric shock was the aversive stimulus used to shape the animals' behavior. Although it is unclear as to how well these shocks were calibrated, different intensities of shock were used to study the effect they had on the mice's learning. The results of this study suggested that when mice are shocked with high-intensity electricity, they are quicker to go the other way, in this case through the white doorway and down the white path, than when one uses low-intensity shocks. This became the first Yerkes-Dodson principle, later becoming a "law" of performance.

Over time this finding, and others, led to the postulate that moderate levels of arousal (often used synonymously with stress) will result in optimal performance, whereas too little arousal or too much arousal will degrade performance -- a curvilinear relationship sometimes termed an inverted U. This general assertion seems to make intuitive sense to most people. In fact, this notion, and arousal theory in general, have likely gained such success for this very reason—it seems as though that's the way it should be. After all, if one lacks motivation or even the most modest amount of arousal to stay focused and get going, one's performance on various tasks is likely to suffer. The inverse of that is equally compelling, with too much exertion or strain, our performance is likely to decrease. But does it accurately portray what science says about stress and performance? The answer is…not exactly.

The Infamous Inverted U

The Yerkes and Dodson experiments later became the foundation on which the curvilinear relationship between arousal and performance was based. The belief in this relationship became so popular and widespread that it has taken its critics the better part of the last three decades to fully challenge it. There have been numerous criticisms of Yerkes and Dodson's experiments, not the least of which concerns the mice-to-man extension of their findings as well as the generalizability of their simple laboratory learning paradigm to real-world complex performance issues. A further criticism concerns Yerkes and Dodson's failure to measure stress (or even arousal) in these mice. Instead, they administered different levels of shock (which, incidentally, have also been criticized for their poor calibrations) that were later interpreted as resulting in arousal or stress in the mice. Certainly, one could argue that electric shock would in many instances increase arousal (surprisingly this is not always the case) and might even constitute stress, but Yerkes and Dodson did not themselves make this claim. However, a large portion of the psychological community concluded that electric shock increased the arousal in the mice, acting as a stressor of different intensities, motivating the mice to learn faster—a contentious and hotly debated issue to this day. The reality is that we don't actually know how aroused, stressed, motivated, anxious, or upset the mice were. This was never measured physiologically or behaviorally. It is interesting to note that subsequent research has found that mild to moderate electric shocks do not necessarily cause arousal in different animals and can be rapidly habituated to in laboratory settings (Hancock & Ganey, 2002; Hancock, Ganey, & Szalma, 2002).

Reviews of this claim (Banich, Stokes, & Elledge, 1987; Stokes & Kite, 1994) report that replication attempts using a variety of animals have repeatedly failed to find comparable results. During Brown's (1965) early critique of the Yerkes-Dodson law (focused mostly on methodological flaws in their design), the author asserted that the "law" should be silenced. Landers (1980) also criticized the hypothesis, noting, "In actuality, the inverted-U hypothesis is not an explanation for the arousal-performance relationship; it merely posits that this relationship is curvilinear without explaining what internal state or process produces it." (p. 346). Further concerns have been raised about the methodology required to either prove or refute the hypothesis since arousal can not be generated in the laboratory per se (it tends to result from some event or condition). That is to say, researchers typically measure physiological reactions to workload and stressful conditions, linking them to arousal as supposed markers, since arousal itself is a theoretical construct. Neiss (1988) suggested that the current research literature in support of the Yerkes-Dodson principle of arousal and performance, "is psychologically trivial" (p. 353). In his review of the inverted-U hypothesis, Neiss disputed the relationship between arousal and motor performance and instead explored a reconceptualization of arousal into specific psychobiological states (an interdependence model between affect, cognition, and such states). Neiss recommended that any investigation of these psychobiological states should optimally include measures that have historically been associated with arousal: respiration, heart rate, electroencephalography, electromyography, etc. (as well as other measures that may discriminate between states).

It should be pointed out that the direction taken with Yerkes and Dodson's work (1908) should not be blamed on those authors themselves. On the contrary, they were rather modest in their conclusions about what they had found. In fact, the field of psychology remained silent on the topic for half a century before Broadhurst (1957) unearthed the finding and raised it to its lawful status. Hancock et al. (2002) point out that during the intervening decades, the curvilinear function of these two

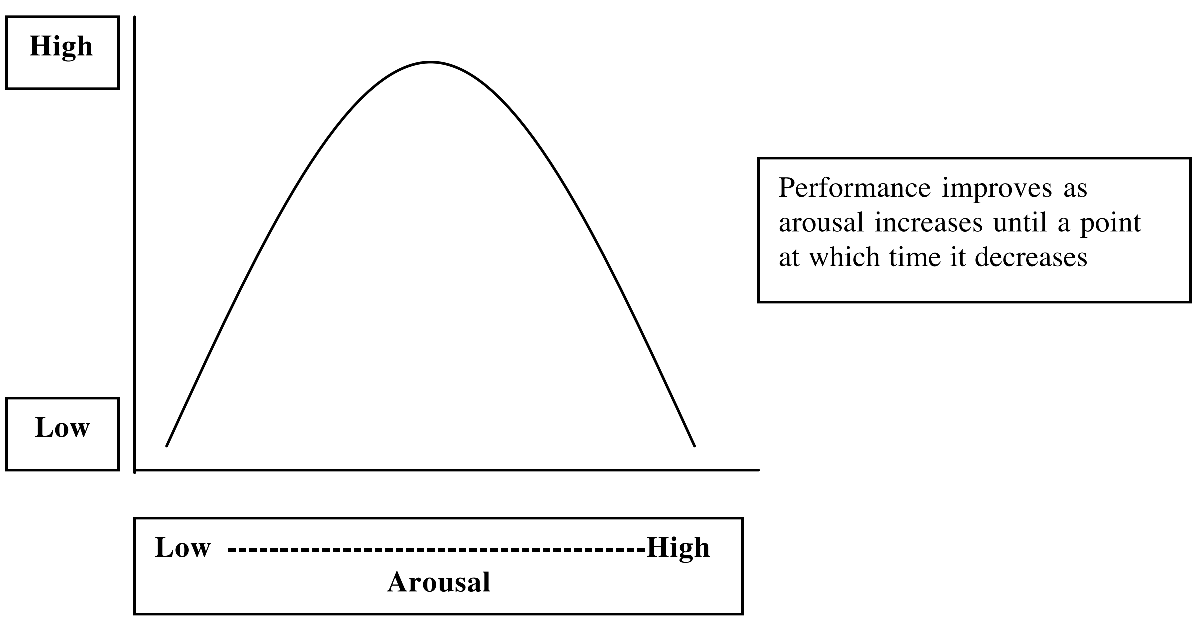

Figure 1. The Yerkes-Dodson principle as it is often shown in various texts.

properties (arousal and performance) remained untouched by the scientific literature. So why is it that this figure (see figure 1) is found in many introductory psychology texts and most books that reference stress, arousal, or performance? There are several reasons, not the least of which is that many researchers found parallels between their work and that of Yerkes and Dodson.

Early on, two competing hypotheses evolved to take the place of emotion literature in the explanation of performance outcome. The first, drive theory (Hull, 1943; Spence, 1951) held that the relationship between arousal and performance was positive and linear. The Hull-Spence drive theory specifically states that an increase in drive (that has become linked by many to arousal) will increase the likelihood that a well-learned response will occur (likely improving performance); whereas arousal will decrease performance of a task that is not well-learned (Spence & Spence, 1966). However, this position gradually fell out of favor due to its lack of empirical support, the difficulty in testing the hypothesis, and the robust anecdotal evidence to the contrary (Neiss, 1988). This allowed the inverted-U hypothesis to gain further support as the predominant framework.

Duffy is cited as one of the major early proponents of arousal and activation constructs (Duffy 1941, 1957). She conjectured that humans organize responses to achieve and maintain equilibrium (based heavily on Cannon's hypotheses). Moreover, she suggested that we tend to be selective in our response to various stimuli and that our attention is directed as a result of our personal goals. She indicated that after evaluating the relationship of elements within the environment we mobilize an energetical system (Cannon, 1915) to meet the demands presented. Duffy implicated arousal in the activation of this system and indicated that it supplied the energy for the organism's behavioral response. Driven by the desire to reduce the number of psychological concepts required to explain such a response, she further contended that these three qualities: directional response, relational evaluation, and energy mobilization, were common to all human responses (Duffy, 1941). In later work, Duffy (1957) provided a review of the experimental support for arousal as a unitary function in the human response system. Taking this notion and the original work of Yerkes and Dodson a step further, she asserted, "In general, the optimal degree of activation appears to be a moderate one, the curve which expresses the relationship between activation and quality of performance taking the form of an inverted U." (p. 268). Thus, the desire for an organizing force and the reduction of unnecessary levels of psychological explanation appear to have fueled early investigations into the role of arousal as the underlying energy system in human performance.

Duffy was certainly not alone in her assertions. During the middle of the last century, Hebb (1955) was examining the relationship between motivation and the nervous system. He characterized this relationship as roughly curvilinear. Falk and Bindra (1954) found that performance on simple tasks, like time estimation, was enhanced through modest increases in arousal (inferred from the threat of pain). Broadhurst (1957) attempted to expand Yerkes and Dodson's principle to include different motivational influences (air deprivation instead of electric shock) and a different population, using rats instead of mice. His findings appear consistent with the curvilinear principle—rats swimming speed while immersed under water increased based on the amount of time submerged up to a point, at which it decreased. Broadhurst concluded that learning has an optimal level of motivation or drive associated with it, and that when motivation exceeds this level, performance suffers. Shortly afterward, Easterbrook (1959), in his seminal paper on the relationship between stress and performance (the effects of emotion on cue utilization), argued that there is an optimal level of stress associated with cue sampling (attention allocation) as one scans and absorbs the various stimuli in his or her environment. Easterbrook (1959) proposed that the effects of arousal under stress were motivational in nature, serving to better organize a course of action, as opposed to emotional, leading to a disruption in performance. This too seemed to adhere to the Yerkes-Dodson principle.

A large body of work by Hans Selye (1956) furthered this concept. Selye published over 1,500 articles and 30 books on the subject of stress and coping, and his work on the Global Adaptation Syndrome (GAS) propelled beliefs in the ubiquitous inverted U. Other authors encouraged the field's adoption of the hypothesis as well. Teichner, Arees, and Reilly (1963) proposed a distraction-arousal theory. They contended that stressors have two primary mechanisms for negatively affecting performance: they either distract the operator, drawing attention away from the primary task or they increase the operator's level of arousal past optimal levels. Turning their focus to affective processes, Schachter and Singer (1962) devised an ingenious experiment aimed at determining the relationship between arousal and cognition in the creation of emotional states. They injected subjects with epinephrine to induce physiological arousal and then exposed them to various social conditions using confederates that provided a model for their cognitive and emotional experience (i.e., acting agitated or joyful). They suggested that emotions were nothing more than generalized arousal added to context-based cognitions. Specifically, they found evidence for the assertion that physiological arousal was necessary but not sufficient for emotion. Similarly, cognition was not enough alone to enact an emotional state either. However, when provided with physiological arousal and explanatory cognitions, individuals experienced emotional states that were congruent with that of confederates. While these findings were later challenged by others (Plutchik & Ax, 1967), they demonstrate the widespread acceptance and propagation of the theory.

During the course of arousal theory's evolution, many have come to view its definitive expression as a physiological one. Given the apparently inseparable state of arousal and stress, researchers commonly link physiologic reactivity to the human stress response. However, Stokes and Kite (2001) report on the misperception of various physiological measures (i.e., corticoids or skin temperature) as necessarily indicators of stress. They note that such measures need not co-vary and are often associated with a variety of positive and negative affective states. Roscoe (1978), in his investigation of this alignment, stated that physiological markers are not accurate measures of emotional stress. This connection has fused in large measure due to Cannon's (1915) efforts to detail the human fight or flight response and Selye's (1956) work on the Global Adaptation Syndrome (GAS). Stokes and Kite (2001) cite Selye's contention that the human response to stress is a nonspecific systemic reaction. This view closely resembles elements in arousal theory and served to support volumes of experimental work in this joint direction. They argue that although nonspecific physiological arousal has become inextricably linked with psychological stress, it is inadequate in its explanation of the human stress response.

Stokes and Kite propose, as Lazarus suggested earlier (1991), that the human stress response may be best envisioned within the context of emotions. In concert with this perspective, they promote the Affect Program Theory (Ekman, 1977) as an empirically grounded framework for the relationship between emotions and stress. This approach suggests that when an event or condition is experienced that is deemed significant to the organism, its features are matched to a pre-packaged template or pattern of adaptations. Specifically, any pattern encountered elicits a prepared physiological response. Each emotion corresponds with, or is contained within, this pre-packaged response. This line of thinking is consistent with that of many emotion researchers who have come to view emotional response as a preparatory step to formulate action. Emotions are seen as managing both motivational resources and regulating behavioral and cognitive activation (Frijda, 1986; 1996; Panksepp, 1996). Stemmler, Heldmann, Pauls, and Scherer (2001) extended this view in their exploration of psychophysiological responses to fear and anger under real-world and imaginal states. They suggest that emotion exists in context-deviation specificity. Specifically, they concluded that each individual has response components within a greater somatovisceral response organization that directs resource allocation based on situational circumstances. Examples of such responses are the activation of behavioral inhibition, approach and avoidance responses, the alerting response, and the defense reflex. According to Stemmler and colleague's framework, these response components would naturally be followed by an, "emotion signature proper" whose primary function is "…to prepare the organism for the emotion-specific, upcoming need to act and to protect itself with a hardwired, fixed somatovisceral adaptation." (p. 290). The authors suggested that Cannon's (1915) fight or flight model would be best reconceptualized as a defensive reflex given the proposed organization described above.

These views are consistent with the work of Thackray (Thackray, 1988; Thackray & Touchstone, 1983) who examined the startle response and its impact on performance. Thackray reported that the startle reflex immediately follows an initial orienting response to an unexpected stimulus, typically within 100 milliseconds after the event. Accordingly, he and others (Landis & Hunt, 1939) have suggested that this reflexive response is likely to be pre-emotional. The authors asserted that the response includes physiological and subjective dimensions. Physiologically, the startle reflex includes a full array of autonomic and central nervous system activation that has been characterized as general and non-specific. The authors theorized that the subjective feeling state induced by the startle reflex is related to fear or anger; however, being pre-emotional, the reaction is believed to be different, in some yet undefined way, than these more advanced affective states. Research on the startle response has convincingly demonstrated its effects on performance (May & Rice, 1971; Sternbach, 1960; Thackray, 1965) and is discussed in a further section of the review.

Certainly there is no consensus concerning emotion's role in the human stress response, nor has there been a more dominant voice than that of arousal theory. There are a variety of inverted-U designs that are depicted in the stress literature, but they all resemble a bell curve or normal distribution curve. Some texts use the term arousal (as the x-axis seen in figure 1) while others choose to call it motivation, stress or even anxiety. However, these are all different constructs and none are definitively tied to Yerkes and Dodson's original work (1908) nor are they explicitly connected to all of the subsequent studies "confirming" the utility of arousal theory. To make the situation worse, much of the time the graphic (the inverted U) fails to make explicit the nature of the performance or stressor in the model. Readers are simply left to assume that this model must apply generically across the gamut of performance possibilities.

Yet the majority of the scientific community today says that this isn't so. Christianson (1992) conducted a rigorous review of the literature on arousal's role in memory function and suggested that it was time to retire the inverted U as it no longer was useful in describing the relationship between stress or arousal and memory performance. Other authors have similarly rejected the common use of this model within a variety of cognitive and physical domains (Stokes & Kite, 1994). Broadbent (1963) argued that since the effects of stressors are different, there may not be a singular mechanism that mediates an individual's reactions to stress. He found that various putative stressors resulted in differing patterns of behavior. For example, loss of sleep affected the speed of performance but not the accuracy of that performance and only typically at the end of a task. Noise affected accuracy but not speed and also only typically at the end of a task. However, heat affected accuracy but not speed and it did so generally at the beginning of a task. Thus, when holding the task constant, these putative stressors revealed different patterns of decrement in performance, which may hint toward different underlying mechanisms—something inconsistent with a unitary arousal explanation. Broadbent's later work (1971) asserted that noise increased arousal which in turn resulted in a narrowing of attention leading to a restriction in the range of information processed. This position is consistent with Easterbrook's earlier hypothesis regarding restricted cue sampling.

This suggests that arousal may have a role to play, perhaps simply as a covariate, in the moderation of information processing that relates to changes in performance under stress.

Although research in this area has supported a number of different conclusions, research specific to cognitive performance generally suggests more of a linear trend under arousal and stress (Broadbent & Broadbent, 1988). Giesbrecht, Arnett, Vela, and Bristow (1993) found that performance on complex tasks like public speaking or math calculations was degraded through increases in arousal, and similar results were reported by Lovallo (1997). However, even this area of study is not immune to divergence. Brookhuis and de Waard (2001) provided support for a curvilinear relationship between stress and performance. They drew a distinction between underload—a condition leading to a reduction in alertness and lowered attention, and overload—leading to distraction and diverted attention. Other research indicates that an idiographic performance profile, tied to the specific stressor and the specific dimension of performance being measured, is most appropriate. Sullivan and Bhagat (1992) reviewed the research literature pertaining to relational models. They suggested that there are a number of different relationships that have empirical support. Some of these resemble skewed versions of the inverted U, others are non-inverted Us, many show linear patterns, and some are even a straight line, showing very little effect of arousal across different intensities and performance

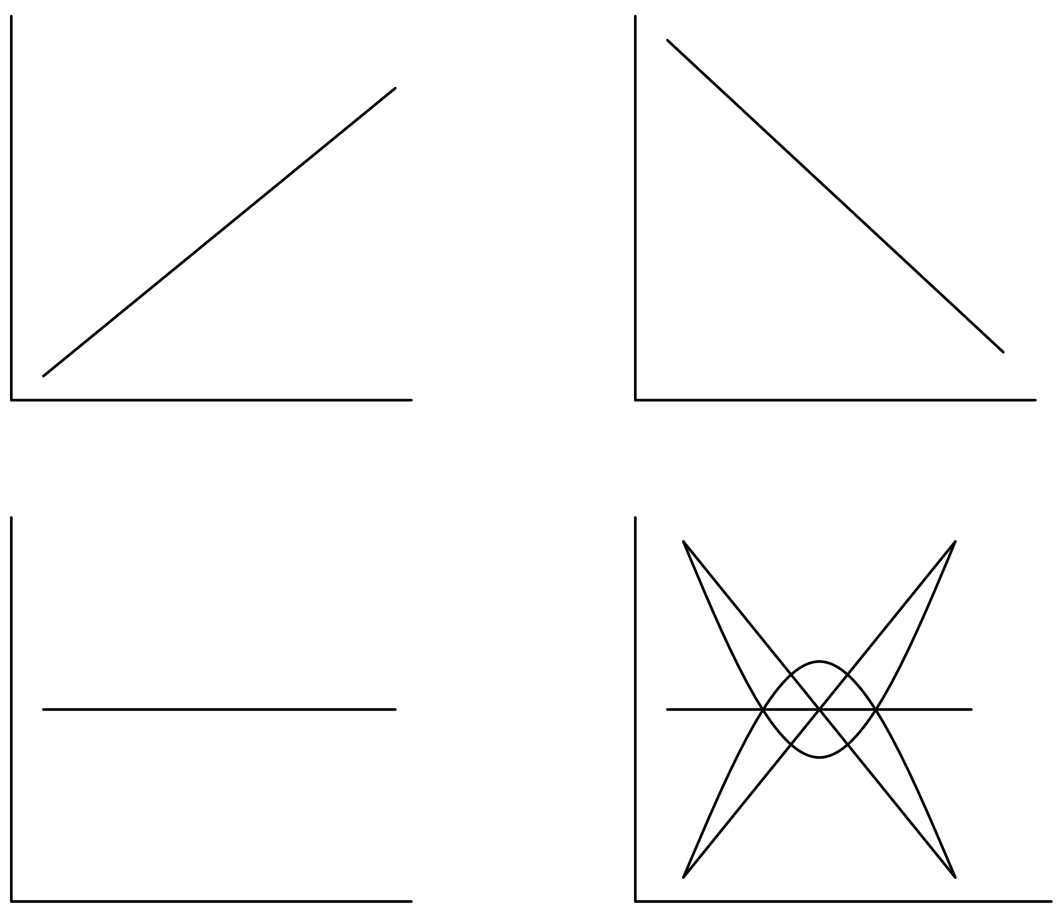

Figure 2. Positive and negative linear relationships are depicted above, the absence of a relationship is shown by the straight line, while a combination of research findings (positive, negative and null) are mapped alongside the curvilinear model proposed by the Yerkes-Dodson principle.

dimensions (see figure 2). Westman and Eden (1996) examined the relationship between stress and performance across a variety of mental domains. These authors tested for the inverted-U hypothesis and the negative linear trend hypothesis. Their results demonstrated support for the latter and not the former. In other words, the research literature addressing this issue remains conflicted.

In any case, the Yerkes-Dodson law and the infamous inverted U seem to have outlived their usefulness as an absolute and unitary theory in human performance. However, if not an overarching theory of arousal, then how should the relationship between stress, the various demands one faces, and human performance be explained? Several authors have approached this question in an attempt to create an adequate replacement for arousal theory. A brief summary of recent frameworks, models, and theories follows.

Theoretical Perspectives of Resource Theory and Activation

Welford (1973) explored three models of stress and performance (arousal theory, signal-detection theory, and the Yerkes-Dodson law) in an attempt to unify them under a new framework. He posited that stress arises when an organism departs from an optimal condition. Drawing upon stress definitions from McGrath (1970) and Sells (1970), he suggested that motivation plays a role in spurring action against this deviation from an optimal state. Welford has not been alone in asserting the strong role motivation may play in performance outcome. Lovallo (1997) suggested that the greater the arousal, the greater the motivation and confirmed this notion with research conducted on the stress or anxiety imposed by public speaking. Welford's observation of an imbalance in the organism's state has been furthered by Hammond (2000) who asserted the Cognitive Continuum theory. This framework is based on two prevailing perspectives, one of Coherence (behavior results from an interaction between cognitive processes and environmental demands), and one of Correspondence (behavior results directly from the demand and the outcome of the response to that demand). According to this theory, stress is viewed as something that breaches the homeostatic relationship between cognition and the environmental demand (the task).

Pribram and McGuiness (1975; McGuiness & Pribram, 1980) proposed that arousal was one of two cortical regulatory systems in the body. According to their framework, arousal is the externally oriented system while activation is the internally oriented system. These authors further delineated three brain-based attentional mechanisms that ground the model in empirically derived neuroanatomical relationships. They posited that the first regulates arousal based on input values (externally oriented). The authors suggested this control function is best associated with the amygdala. This assertion is heavily based in a review of amygdalectomy research that has found a consistent pattern of the amygdala's role in both facilitating and inhibiting physiological arousal. The second mechanism is located within the basal ganglia and has been implicated in the control of the organism's preparatory response system—referred to as activation. This connection draws on the voluminous literature detailing the orienting response. Finally, Pribram and McGuiness' third mechanism coordinates the former two, arousal and activation. This final system is believed to be associated with the hippocampus (based at least in part on a review of hippocampalectomy research findings). One of its primary functions is to separate the stimulus and its response through the re-organization of amygdala and basal ganglia mechanisms. The authors suggested that this process is best described as the application of effort. Their investigation provides a detailed description of the neuronal systems and corresponding research that offer support for the relationships described above.

Hancock and Warm (1989) formulated their own arousal replacement framework. In their model these authors described the "trinity of stress" as consisting of input features (environmental stressors), adaptation features (cognitive appraisal), and output features (changes in bodily functions and ultimately performance efficiency). After reviewing the stress and human performance literature, Hancock and Warm concluded that every stressor produced a unique array of effects on both cognition and performance. This led them to agree with Broadbent (1963) surmising that it may not be possible to find a unitary governing theory. Wofford and Daly (1997) also defined the human stress response as constituting three domains: physiological arousal (i.e., heart rate, blood pressure, temperature, etc.), psychological responses (i.e., dissatisfaction, anxiety, sleep problems, depression, irritation, etc.), and behavioral responses (i.e., job performance, drug abuse, eating disorders, aggression, poor relations, etc.). Although not attempting to apply a unitary model, their division of the stress response represents a convergence among many researchers—outlining physical, cognitive or psychological, and behavioral or performance characteristics.

One traditional theory of cognitive science dictates that there are three levels of explanation that can be used to understand cognitive phenomena: biological, symbolic processing, and adaptive (Newell, 1980; Pylyshyn, 1984). For example, noise may be seen as affecting cortical arousal, causing the redistribution of processing resources, or it may affect the personal meaning of the task leading to a change in motivation (Matthews, 2001). One theory that has been linked to all three of these levels is resource theory. Resource theory suggests there is a general reservoir of mental resources that can be drawn from to assist the organism in completing task demands. From a theoretical perspective, this pool of resources is believed to vary in amount based on the arousal of the individual (Kahneman, 1973; Mandler, 1979). Szalma and Hancock (2002) provided an overview of the concept and its development. They point out that various metaphors have been used to describe resources, hydraulic and thermodynamic principles have been the most common. It has been suggested that the cognitive structures responsible for information processing are in fact the resources described although this can not be established given the state of current research capabilities.

Kahneman (1973) is frequently cited as the progenitor of the limited-capacity resource model, although Norman and Bobrow (1975) are typically credited with coining the term. Specifically, Kahneman posited that there is a limited pool of mental resources that can be divided across tasks. Thus, when considering concurrent task management, Kahneman suggested there is likely to be an attentional conflict created between the demands of the competing tasks. He asserted that this conflict is due to the dual demand on resource allocation (from the primary to the secondary task). Wickens (1984) suggested that resources can be considered synonymous with a number of terms such as capacity, attention, and effort. He indicated that these concepts all refer to the "…underlying commodity, of limited availability, that enables performance of a task." (p. 67). Kinsbourne and Hicks (1978) argued that resources can be construed as competing for actual cerebral space. Others have tied the brain's metabolism of glucoproteins and changes in blood flow to resource management and consumption (Gur & Reivich, 1980; Sokoloff, 1975).

Fairclough (2001), in his review of compensatory models of effort (related to fatigue), indicated that Kahneman (1973) was the first to conclusively link mental effort to attention control within an information processing model. He asserted that Kahneman's basic premise was that task demands were defined by the amount of effort required and that failure to provide that level of effort resulted in performance decrements. Fairclough suggested that the regulation of mental effort at the principle level is performed on the basis of subjective appraisals of the task demands, the individual's current performance level, and a self-appraisal of stress and comfort. Evidence supports the notion that this self-assessment becomes more inaccurate with greater stress: "the appropriate regulation of mental effort hinges on the reliability of feedback by self-monitoring and appraisal." Fairclough argued that "an increase of mental effort is associated with an increased fidelity of self-monitoring, effective memory retrieval, and analytical processing of a problem space." (p. 491). From this perspective, then, mental effort is a finite resource that is regulated (invested or conserved) and may be synonymous with the regulation of attention.

Yeo and Neal (2004) have also examined the relationship between effort (how hard someone tries to do something) and performance. Although little is known about how effort and performance are directly related, the authors state that "motivation is assumed to affect performance by influencing the way that individuals allocate effort to tasks. The majority of motivation research has concentrated on assessing the predictive strength of motivational interventions, such as goal setting, or constructs, such as valence and self-efficacy, that are thought to influence the allocation of effort to tasks." (p. 231). The authors note several assumptions that underlie this view of effort and performance. For instance, task difficulty is believed to relate to the amount of effort that is allocated to the task (assuming that the more difficult the task, the greater the effort allocation). Yeo and Neal's review of this literature highlighted several key findings: 1) an individual's employment of effort depends on his level of skill on a task and his rate of learning, 2) when faced with novel tasks, effort tends to initially increase until greater familiarity with the task is achieved, 3) perceived task difficulty and effort are highly correlated which may suggest they share an underlying construct, and finally, 4) effort changes throughout skill acquisition and these changes appear related to cognitive ability and goal orientation.

Resource theory has found support among a large cross-section of the research community. While attempting to create a power function to predict psychophysical workload, Gopher and Braune (1984) found a strong correlation between the task difficulty index (based on task characteristics) and a measurement of invested resources (based on subjective measures). They concluded that their data strongly supported Kahneman's (1973) resource model. Consistent with this perspective, Neuberg and Newsom (1993) asserted a cognitive structuring model that explains the effects of stress on various elements of cognition. They indicated that the creation and use of schemas, prototypes, scripts, attitudes, and stereotypes helps to reduce cognitive load, which draws upon this finite pool of resources.

Wickens (1984; 1991; 1992) has worked extensively on both attentional capacity theory and an expansion of this framework as a revision of resource theory. Wickens (1991) defined resources as "…a small set of scarce commodities within the human information processing system, which is associated with a distinct physiological structure, and with physiological arousal changes as increased demands are placed on it." (p. 22). He has also asserted that resources can be mobilized voluntarily and allocated in regulated quantities as needed for task completion. Describing the specific mechanism and structures under which these processes function is a bit more difficult; however, based on earlier resource capacity frameworks, Wickens (1991) introduced a multiple resources model: "the resource concept is founded on the underlying assumption that the human operator has a limited capacity for processing resources that may be allocated to task performance." (p. 4). He illustrated this model using concurrent task management. Wickens suggested that three possible factors were engaged in concurrent task management performance outcomes. The first was confusion. He defined the confusion of task elements as a condition where similar tasks often interfere with performance while more distinct tasks degrade performance less often. The second potential outcome is cooperation. The cooperation between task processes can be seen when high task similarity yields combined results (i.e., tracking a ball as you prepare to hit it with a racquet). Finally, there also can be competition between demands. Competition for resources, specifically resource allocation to one task versus another, results in diminishing resources from the other task(s) being managed. Wickens has argued that timesharing (cooperation) improves between tasks to the extent that they use separate versus shared resources. Wickens (1991) has drawn a very distinct parallel between mental effort and resources. In diagramming the relationship between performance, task difficulty, and resources, he asserted that Performance = Resources / Task Difficulty. Thus ultimate performance can be described (not predicted) by assessing the amount of resources remaining after having been divided by the difficulty of the task.

Several theorists have attacked the suggestion that there is a general reservoir of resources (Allport, 1980; Neisser, 1976) used for information processing and others have suggested there may be multiple pools of resources as opposed to s single pool (Marsh, Hicks, & Cook, 2004). Navon (1984) examined the notion of resources and the assumptions made by resource theory. He challenged the idea that such resources were limited in nature, stating, "…the existence of resources of limited quantity serving as mental input to processing is a *theoretical claim* that should be put to empirical test." (p. 217). During his review of the theory, Navon pointed out the many enticing features of resource theory that frame the various effects found in the research literature. For instance, he observed that motivational level can be readily seen as a regulatory agent involved in the allocation of resources to a task, that task difficulty can been seen as a modulator of the efficiency of a resource in its production or output, and that task complexity, "…may be regarded as tapping the load imposed by the task and thereby the amount of resources." (p. 219). Furthermore, from this perspective, dual-task deficits may be viewed as degrading performance on the primary task as a result of a reduction in the resources activated. In addition, bolstering the priority given to the concurrent task may also reduce the resources available to the primary task and a similar effect may be incurred by varying the concurrent task's difficulty. It is generally assumed that the more complex the task, the more resources it consumes (Gopher & Braune, 1984).

All of this said, Navon contends that there are many limitations and difficulties with the theory that have not been resolved. For instance, there are no reliable tools at our disposal to validate the claims listed above. Also, the theory as posited is unfalsifiable. The author concluded that a limited-capacity resource theory is no more explanatory than an unlimited-capacity resource theory. Thus, without clear empirical validation of its explanations or predictions, Navon stated resource theory "…may turn out to be excess baggage." (p. 216).

Matthews (2001) also provided a critique of resource models, concluding that they tend to be somewhat ambiguous at an explanatory level, suggesting that their usefulness remains descriptive. He proposed that there are three potential bases for the relationship between the resource model and the outcomes it describes. First, there may be an actual change in the parameters of the information processing architecture. That is to say, stressors may change the total quantity of resources available at any given moment. Resource loss may occur as a result of changes in biological or neural functioning (i.e., thermal stress leads to a breakdown in thermal regulation). Second, changes in task demands may occur. Specifically, a processing distraction may interfere with task-related performance (i.e., multiple tasks may overload the processing of information). Finally, changes in strategy may occur. The suggestion here is that the strategic allocation of resources across different task components may change. Matthews indicates that this type of change is likely a consequence of emotion-focused coping.

Energetical Models

Hockey (1984; 1997) presented a framework for the analysis of the effects of stress and high workload on human performance based on Broadbent's (1971) and Kahneman's (1973) models, combining energetical and informational processes. Hockey proposed that activation or energetical processes are allocated, controlled, and subjected to resource management decisions. His model assumes that behavior is goal-directed and self-regulated and that this regulation incurs costs to other parts of the system.

Gaillard and Wientjes (1994) presented their own conceptual framework for mental load (objective demands imposed by a task or subjective ratings of task demands) and stress (input demands or environmental factors, output responses, state feelings, or processes). These authors identified two different types of energy mobilization systems: effort (dominated by the adrenal-medullary system and catecholamines) and distress (dominated by the adrenal-cortical system and cortisol). This formulation is similar to Karasek and Theorell's (1990) model of activity and strain. From this perspective, mental load-related energy mobilization is associated with activation states while stress-related mobilization is associated with disorganized states.

Gaillard (2001) put forth a theory of energetic mechanisms that focuses on the way in which our body regulates states of activation needed to perform and process. Unlike the various resource theories (Kahneman, 1973; Sanders, 1983; Wickens, 1991; 1992), this model is focused on regulatory processes and not the availability of supplies. Gaillard's perspective on the role of a regulated energy mobilization process is shared by many others (Dyregrov, Solomon, & Bassoe, 2000). Consistent with the Gaillard and Wientjes' (1994) framework, Gaillard (2001) views arousal as an activating or energizing force. He favors the term energetics in describing the regulation of information processing, preferring it over arousal, effort, fatigue, and activation because it does not have any specific theoretical connotations. Gaillard believes that these energy mobilizations typically occur under one of the following conditions: 1) task-induced situations—in which activation results from the stimulation of the task or environment itself, 2) internally guided mental effort—a voluntary mobilization under a given mental load, or 3) under periods of emotional arousal—during stressful or threatening situations.

Gaillard (2001), after reviewing the research literature, concluded that stress had several dimensions, including 1) an input function (work demands, emotional threat, or adverse environment), 2) an output function (pattern of behavioral, subjective, and physiological responses—strain), 3) an affective state (in which one feels strained and threatened subjectively), and 4) a process (resulting in a degraded work capacity). He also argued that complex or novel tasks require greater resources than do simple, well-trained tasks. His research has helped to reveal that a "try harder" effortful response can sustain performance for brief periods prior to incurring high physiological and psychological costs (measured via strain and fatigue). He has also found that intense and negative emotions have a deleterious impact on performance in three ways: they disrupt state regulation, they distract the processing of task information, and they cause psychosomatic complaints that demand attention. For example, anxiety is an emotion that takes, in Gaillard's language, "control precedence"—continually begging for attention, reducing the capacity available for processing task-relevant information.

Gaillard (2001) distinguished between mental load and stress. In terms of energy mobilization, mental load manifests itself as normal mental effort (a healthy coping strategy) while stress is seen as enhanced activation that fails to improve performance. Similarly, state regulation, when viewed relative to mental load, is seen as a temporary condition that assists task completion and then returns to normal. On the other hand, stress's activation is not controlled by the task demands and fails to facilitate recovery. Gaillard viewed one's mood as arising from the positive emotions associated with challenges under mental load versus stress's negative affectivity which results from threat perceptions. Finally, the author asserted that coping strategies also differ significantly between these two processes. Under mental load, coping tends to be task-focused while under stress it tends to be emotion-focused.

Direct and Indirect Effects of Putative Stressors

There is significant inconsistency among researchers concerning the direct and indirect effects of various putative stressors. Direct stress effects are those incurred by the task load alone irrespective of any psychological stress that may also be generated. Accordingly, indirect stress effects are those that evolve out of psychological factors associated with the task load demands. There is a fine line that separates these two, and they can be indistinguishable at times. This fact has made their separation and measurement particularly difficult. There are several issues at the heart of the inconsistencies found in the literature. For example, is the application of some task demand (i.e., workload or time pressure) an application of stress? Many would argue that it is while others would contend the contrary. Proponents of the former typically offer one of two arguments. The first argument states that stress is a term that can be applied to any demand on a system. Therefore, any task that requires mental resources qualifies as a stressor—it places a demand on the system. This argument meets the criteria of early stress definitions (stimulus-based approaches); however, it is no longer as accepted given the widespread belief that stress is transactional in nature. The second argument proposes that demands incur a psychological cost in addition to their direct effects. That is to say, these demands trigger a psychological response such as frustration, anxiety, or psychological discomfort. This response often contains both physiological and mental components that vie for resources. In this way, stress acts as a secondary workload factor drawing resources away from the primary demand, devoting them instead to secondary psychological processes.

On the other hand, a compelling argument can be made that workload is a demand that does not require, nor regularly incur, a secondary psychological cost. In applying the stated definition of stress—the interaction between three perceptions: a demand, an ability to cope with that demand, and the importance of being able to cope (McGrath, 1976), it's difficult to see how demand characteristics alone qualify as stressors. For example, in some circumstances time pressure and/or workload would trigger anxiety or frustration that might further distract or interfere with performance. However, it is not clear that this would necessarily be so in most, let alone all, situations.

If we agree that subjective experience and specifically cognitive appraisal (a transactional model assumption) is elemental in defining stress, then one must assume it plays a significant role in answering questions about whether workload, time pressure, or other putative stressors carry both direct and indirect effects. Does this suggest that when a demand is deemed stressful or upsetting it is necessarily a stressor, regardless of the objective outcome? If an increase in workload does not impair performance yet is viewed as stressful by the operator, does this indicate that it should be considered a stressor? Reasonable arguments can be made to support both positions, and the research literature, in its current state, is a reflection of this fact. Although it can be argued that each "stressor" involves direct effects, each may also carry indirect effects as well. For example, time pressure limits the time available to perform a given task. This limit is a physical boundary that does not require any psychological explanation in understanding its direct effects on performance. However, this limitation often evokes a corresponding psychological reaction such as anxiety that has secondary or indirect effects on performance. The ability to separate these two dimensions has proven difficult for the research community. The research that addresses various putative stressors discussed in the review (e.g., workload, time pressure, heat and cold, noise, and fatigue) rarely makes the distinction between these two dimensions, given the inherent difficulty in doing so. Therefore, discussions of these factors in this review comprise both direct and indirect effects, without distinguishing between them.

Workload as a Substitute for Stress

Several researchers have attempted to side-step the inter-relationship between direct and indirect effects by relying on descriptions of workload alone, ignoring potentially related psychological stress

(Hancock & Desmond, 2001). In doing so, they have circumvented a direct discussion of stress and its role in performance degradation or enhancement. However, in leaving this issue unaddressed, these authors have left the reader to infer a stress effect in many instances, correctly or not. I have not attempted to resolve this issue but to make the reader aware of it.

Andre (2001) defined workload as, "…a hypothetical construct that represents the cost incurred by a human operator to achieve a particular level of performance." (p. 377). Kahneman (1973) considered workload to be a primary source of resource depletion and defined it as "…the proportion of the capacity an operator spends on task performance." Kantowitz and Simsek (2001) defined it as, "an intervening variable that modulates the tuning between the demands of the environment and the capabilities of the organism." They indicated that this variable, being theoretical in nature, "…cannot be directly observed but must be inferred from changes in performance." (p. 405). The central purpose of workload as a construct was provided by Gopher and Donchin (1986) who suggested that it was "…intended to capture limitations on the operator's information processing apparatus as…viewed from the perspective of some assigned tasks." Lastly, Wickens (2001) favored Moray's (1979) definition of mental workload; "…an inferred construct that mediates between task difficulty, operator skill, and observed performance." (pp. 443). These definitions of workload are very similar to early conceptions of stress—an interaction between demands and resources (the stimulus-based approach). The most noticeable feature here is the absence of any explicit cognitive function such as appraisal. However, one shouldn't conclude that workload simply constitutes the demands of a given task. On the contrary, the dominant perspectives in the field cited above provide ample evidence that workload is believed to be much more than that. Unfortunately, once researchers go beyond the most elementary description of the term, confusion over its meaning rises rapidly.

In response to this confusion, Hilburn and Jorna (2001) differentiated between workload and task load. They suggested that task load should be defined as the demand imposed by the task itself, and they conceive of workload as the subjective experience of the task demand. Parasuraman and Hancock (2001) made a similar differentiation in their dynamic and adaptive model of workload: "Workload may be driven by the task load imposed on human operators from external environmental sources but not deterministically so, because workload is also mediated by the individual response of human operators to the load and their skill levels, task management strategies, and other personal characteristics." (p. 306). The authors defined task load as what the work or tasks bring as environmental loads on the organism or system while workload concerns what is experienced by the organism or system as it attempts to adapt accordingly. These two sets of definitions illustrate the continued overlap between direct and indirect stress effects in the research literature.

Hendy, Farrell, and East (2001) presented an information processing model of operator stress (defined by time pressure) and performance. These authors posit that the underlying stressor that determines operator performance, error production, and judgments of workload is time pressure. In fact, according to Hendy et al. (2001) all factors affecting workload are reduced to this variable. These authors have proposed the following algorithm for the theoretical calculation of the relationship between any given task load and its corresponding time pressure:

$$\text{Task load} \div \text{processing rate} = \text{decision time}$$

$$\text{Decision time} \div \text{time available} = \text{time pressure.}$$

Hendy et al. suggest three possibilities by which human information processing can reduce information processing load mismatch. The first is a reduction in task load or the amount of information. The second is an increase in the time available to complete the task, and the third is an increase in channel capacity (regulating the rate and volume of information processing). Hendy et al. are certainly not alone in their alignment of time pressure and workload. O'Donnell and Eggemeier (1986) also drew a direct connection between workload and time pressure which they believed was likely to lead to load-shedding (this topic is addressed further in a later section of the review).

Measurement of Stress and Workload

Muscio (1921) stated that to define any phenomenon one must be able to measure it first. Thus a reliable and valid tool of measurement must exist a priori; however, it is difficult to create such a measure without knowing what you are trying to measure. This quandary has led many researchers to conclude that the pursuit of task-demand measurements is more feasible; however, others have decidedly tackled the amorphous construct of stress itself.

Gopher and Braune (1984) discussed the use of subjective measurements of workload. Their review of research in this area showed it to be consistently undecided. Some research demonstrated a strong relationship between subjective ratings and objective indices and others a very weak relationship. For example, Shostak and Peterson (1990) failed to find any significant correlation between physiological arousal induced from mental arithmetic and self-reported feelings of anxiety while Zeier (1994) found significant correlations between workload and cortisol release. Krausman, Crowell, and Wilson (2002) reported finding physiological arousal measures that corresponded to both the perceptions of exertion and cognitive performance decrements. In light of the inconsistent connection between objective and subjective measures, Stokes and Kite (2001) have cautioned against the presumption that physiological indicators are necessarily related to stress. Kantowitz and Casper (1988) suggested, "We may never be able to create a meaningful and valid scale for mental workload equivalent to kilocalories per minute in terms of its utility, generality, and formal measurement properties." (p. 164).

Backs (2001) modeled physiological markers of workload (i.e., heart rate and respiration period) patterned after the work of Cacioppo and Tassinary (1990) who addressed the potential problems that exist in linking physiological and other data together in causal relationships. Based on their review, they concluded scientists in various fields desire to use physiology as a measurable index of the state of the organism. However, they caution that when there is a relationship between a process or event and a concomitant physiological change, there are numerous possible causal explanations. Furthermore, underlying causal explanations of relationships are rarely presented. Rarer yet is the demonstration that physiological variation reliably predicts psychological variation. These authors provided a framework to help establish such relationships. This framework constitutes four classes of psychophysiological relations, each of which is integrated into a multi-dimensional matrix consisting of configural, temporal, specific, and general forms of relational elements. A given relationship (e.g., pupillary dilation and workload) can be analyzed using this matrix. For example, if greater pupil dilation occurs under increasing workload, one could characterize the relationship as concomitant and corollary according to Cacioppo and Tassinary's model. However, the relationship would be characterized differently if, for instance, pupil dilation did not consistently increase as workload increased, or if dilation increased differently between conditions or individuals. The authors' framework accommodates context-specific relationships across a number of dimensions in the hope of capturing the possible range of relations, including those considered to be unrelated elements to those that are causal in nature.

Hancock, Mechkati, and Robertson (1985) also explored various measurement methodologies of mental workload during which they stated, "…mental workload presumably affects the activity of the CNS [central nervous system], measures may variously reflect processes such as demand for increased energy, progressive degradation of the system, or homeostatic action of mechanisms designed to restore system equilibrium disturbed by such cognitive task requirements." (p. 1110). These authors defined mental workload as the result of CNS activity that is purposeful. Beatty (1982) found evidence that pupil dilations were closely related to changes in information processing, and presumably, increased resource mobilization (changes correlated with increases in task difficulty).

Hancock and colleagues (1985) suggest that there are two useful dimensions in considering measurements of mental workload. The first refers to the workload's practicality—how practical is the measure under working conditions. The second dimension concerns spatial and systemic congruence—how proximal is the measurement to the site of the mental activity. In their analysis of various physiological measures, these authors investigated the research findings associated with the following covariates: auditory canal temperature, event related potentials, flicker fusion frequency, critical fusion frequency, galvanic skin response, electrocardiogram, heart rate variability, electromyography, muscle tension, electroencephalographic activity, eye/eyelid movement, pupillary dilation, respiration analysis, and body fluid analysis. Of these measures, event related potentials were determined to have the greatest spatial congruence (they were the most proximal to the site of mental activity) and were relatively practical while heart rate variability was deemed to be the most practical with reasonable spatial congruence. It should be noted that these authors did not attempt to independently validate these measures experimentally, nor demonstrate their relative predictive nature.

Brookhuis and de Waard (2001) suggested that there were three major categories of measurement information in the field on transportation human factors: task performance, subjective report, and physiological data. In their review of measurement tools they found the SWAT (subjective workload assessment technique) and the NASA-TLX (task load index) were the most commonly used self-report indices of mental workload. Further, they indicated that electrocardiogram was the most commonly used physiologic data point (measuring heart rate and heart rate variability). In addition, they found that facial muscles as well as brain activity measures (electroencephalography) and blood assays of catecholamines have emerged as reliable covariates of mental effort. According to the authors, this evidence supports the notion that such measures can serve as indices of mental effort during task performance.

Andre (2001) preferred the measurement of task demands as opposed to stress per se (side stepping the complication of the construct all together). He outlined various measures for workload listed below (Table 1 is a modified reproduction from Andre, 2001).

Table 1. Andre's Measurements of Task Demands.

Category	Dimension	Measurement method
Physical	physical effort	subjective
	twisting/reaching	observation, instrument, subjective
	dexterity	observation, subjective
	force	instrument, subjective
	comfort	instrument, subjective
Physiological	pain/sensation	observation, subjective
	heart rate	instrument
	temperature	instrument
	metabolic rate	instrument
Psychological	cognitive demand	subjective
	perceptual demand	subjective
	memory demand	subjective
	locus of control	subjective
	familiarity	observation, subjective
	predictability	observation, subjective
Emotional	stress/anxiety	observation, instrument, subjective
	frustration	observation, subjective
	intrigue	observation, subjective
	excitement	observation, subjective

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Hilburn and Jorna (2001) explored the subjective and objective workload of Air Traffic Control (ATC) personnel. In their analyses, they found that the best predictor of workload for ATC was the traffic load, specifically, the number of aircraft managed by the controller. Other factors that they believed to contribute to ATC workload and the overall airspace complexity of ATC tasks included: the number of flight altitude transitions, mean airspeed of the aircraft, the mix of aircraft, direction variations, the proximity of aircraft, and finally, the weather. These authors also generated a list of workload measures used in ATC research (subjective, behavioral, and psychophysiological). Table 2 from the authors' work has been reproduced below. The authors found that most ATC measures have relied upon subjective report.

Table 2. Hilburn and Jorna's Air Traffic Control workload measures.

Subjective
NASA-TLX (Brookings, Wilson, & Swain, 1996; Hooijer & Hilburn, 1996)
Air Traffic Workload Input Technique (ATWIT: Leighbody, Beck, & Amato, 1992)
Subject matter expert / Over-the-shoulder ratings (Schaffer, 1991)
Instantaneous Self Assessment (ISA) technique (Eurocontrol, 1997; Whittaker, 1995)
Behavioral
Number of control actions (Mogford, Murphy, & Guttman, 1993)
Communications efficiency (Leplat, 1978)
Communication time, message length (Stein, 1992)
Flight data management (Cardosi & Murphy, 1995)
Intersector coordination (Cardosi & Murphy, 1995)
Psychophysiological
EEG, EMG, and EOG (Costa, 1993)
Heart rate measures (Brookings, Wilson, & Swain, 1996; Hooijer & Hilburn, 1996)
Eye blink rate (Brookings, Wilson, & Swain, 1996; Stein, 1992)
Respiration (Brookings & Wilson, 1994)
Biochemical activity (Costa, 1993; Zeier, 1994)
Pupil diameter (Hilburn, Jorna, & Parasuraman, 1995)
Eye scanning randomness (entropy: Hilburn, Jorna, & Parasuraman, 1995)
Visual fixation frequency (Hilburn, 1996; Stein, 1992)

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Hilburn and Jorna (2001) also constructed a framework of system and operator factors contributing to task load and workload in ATC functions (see figure 3).

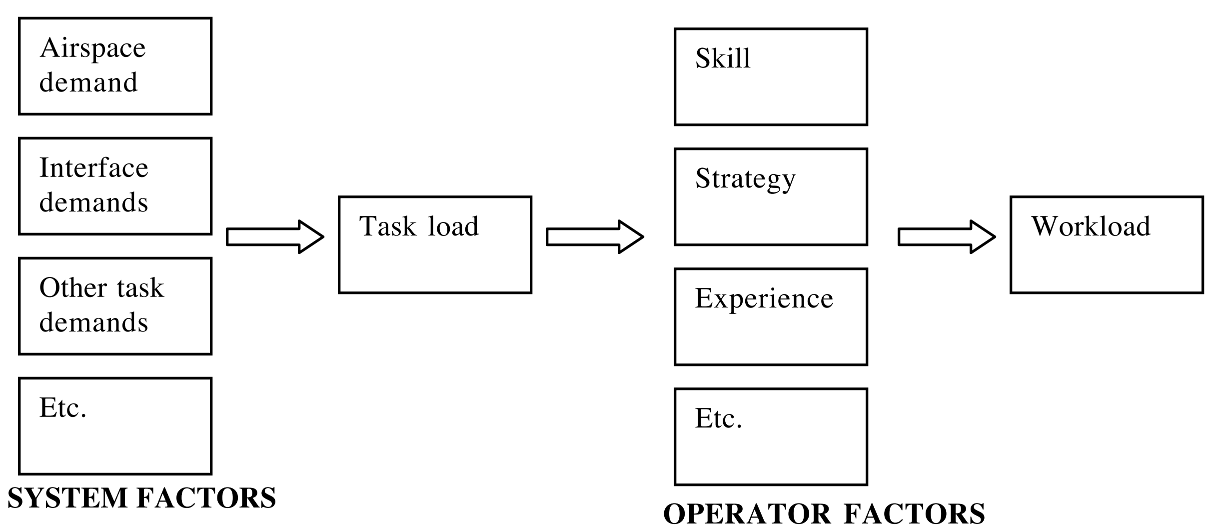

Figure 3. Reproduced from Hilburn and Jorna (2001, figure 2.9.1, p. 386).
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Summary of Findings and Limitations to the Literature

Stress will likely remain an amorphous concept used diversely across popular culture and the scientific community. The theoretical mechanisms that underpin assumptions concerning activation, arousal, effort, motivation, and the like converge in general terms yet diverge rapidly when discussed in detail. Furthermore, statements regarding these processes and systems at the level of neuroanatomical structures and biology are currently tentative at best. Given these difficulties and the limitations of our science for the measurement and study of these constructs, it would be a mistake to suggest that we are now able to measure what we yet struggle to define.

Various models and frameworks attempting to describe, and in some cases predict, human performance under stress continue to be published. The range of these contributions is large and incorporates mathematical models, estimations of cognitive architecture and workload (Leiden, Laughery, Keller, French, Warwick, & Wood, 2001; Neufeld, 1999) as well as theoretical frameworks including social and cognitive moderators, schemas, scripts, and attitudes (Hancock, Ganey, Mouloua, Salas, Gilson, Greenwood-Ericksen, Parasuraman, Harris, Leon, & Smith, 2002; Hancock, Ward, Szalma, Stafford, and Ganey, 2002; Neuberg & Newsom, 1993). However, it is unclear to what extent these models are propelling the scientific community further or simply repeating and repackaging previous contributions to the literature.

In summation of the review, a framework has been constructed that attempts to address the processes and mechanisms associated with cognition under stress. Prior to the presentation of this model, a review of the literature on the effects of stressors on human performance is provided.

Evaluation and Appraisal Systems

Cognitive Appraisal and the Transactional Model

Increasingly, transactional models that incorporate cognitive appraisal as a necessary element in human performance and information processing are becoming widely accepted. Many studies have demonstrated that evaluations of threat and/or controllability are clearly related to the experience of subjective distress. To what degree these evaluations are also directly related to improvements or decrements in performance is less clear. In general, appraisal affects performance the way we might expect it would—negative evaluation often leads to negative outcome while positive evaluation appears to improve task performance (it reduces subjective distress as well as objective performance). When this evaluation occurs and at what level of cognition remains under some debate. However, much of the research seems to point to an initial early evaluation followed by a more involved higher-order cognitive process. The main purpose of this initial evaluation appears to be a preparatory one, facilitating the quick orientation and organization of the individual's response to the stimulus.

The Evaluative Reflex

Neuroscience and biopsychology have transformed our understanding of brain behavior, and stimulated our thinking about the evolutionary functions of neural systems. Crawford and Cacioppo (2002) examined the asymmetrical and negative bias that humans have toward the automatic processing of information. They assert that, "affective responses organize experience by directing attention and processing resources to those aspects of the environment that have important implications for the perceiver. Experiences that evoke affective responses are often better remembered than neutral, nonaffective experiences." (p. 449). Such assertions directly relate to the way in which we perceive and appraise situations and have a strong part to play in the transaction between person and situation. Their argument, grounded in bio-evolutionary psychology, points out, “where positive affect may signal opportunity, negative affect may signal danger. In terms of survival, it is more important to escape from danger than to pursue an opportunity, and it is easier to recover from a missed opportunity than from a failed escape.” (p. 449). Thus, these authors conclude that humans are spring-loaded to evaluate the environment and that this evaluation likely takes place subcortically, prior to any conscious awareness of emotion or higher-order cognition occurring.

They are not alone in their beliefs concerning this early evaluative process. Duckworth, Bargh, Garcia, and Chaiken (2002) assert that individuals engage in a process of initial appraisal that precedes more developed cortical evaluation: “…evaluative responding can be immediate, unintentional, implicit, stimulus based, and linked directly to approach and avoidance motives.” (p. 513). This notion is not new. Zajonc (1980) suggested that evaluative processing is independent of cognition. Decades earlier, Osgood (1953) stated that such initial evaluation was a preparatory move by the organism in order to establish an appropriate behavioral response. The research literature has provided demonstrable support, suggesting that stimuli are evaluated automatically (Bargh, Chaiken, Govender, Pratto, 1992; Bargh, Chaiken, Raymond, & Hymes, 1996; Fazio, Sanbonmatsu, Powell, & Kardes, 1986). It is the speed at which these evaluations (to both novel and well-learned stimuli) occur that has led most researchers to conclude that such responses occur too quickly to result from retrieval processing (300–500ms).

Schupp, Junghofer, Weike, and Hamm (2003) came to similar conclusions after investigating electrocortical activity during the processing of emotional images using ERP (event related potentials) and fMRI (functional magnetic resonance imaging). Their findings suggest that processing of emotional images is related to the degree to which individuals are emotionally engaged by the stimuli. Those with strong affective cues were processed more, for both pleasant and unpleasant images. It was determined that selective attention to the stimulus’ location occurred within 100ms and that attention to its features such as color, orientation, and shape occurred between 150 and 200ms. Thus it would seem that such discrimination is not the result of voluntary orienting, but instead a process of reflexive attention.

Dijksterhuis and Aarts (2003) explored the idea that human perception evolved to preferentially detect negative stimuli over positive stimuli. Their work appears to confirm this notion. Specifically, they found that negative words are detected faster than positive words. In addition, they determined that negative words are detected more accurately than positive words and categorized accordingly. Finally, their results suggest that individuals are better able to detect negative words than positive words based on the affective response detected and not based on the superiority of semantic processing. Additionally, it was found that negative stimuli demand more attention than positive stimuli (presumably taking greater time to process due to the depth at which they are processed), yet individuals appear to require, “less stimulus input to detect a negative stimulus than to detect a positive stimulus.” (p. 17).

Higher-order Cognition and Stress

Assuming that some form of early evaluative reflex does occur, it seems reasonable to conclude that this process is followed by a higher-order cognitive evaluation. Lazarus (1966) is credited as one of the first to assert the notion that psychological stress occurs in individuals who view situations or circumstances as threatening or negative. He and his colleagues further suggested that events themselves do not actually create stress until they are appraised as threatening (Lazarus, 1990; Lazarus & Folkman, 1984). Moreover, Lazarus argued that psychological stress required one to perceive one’s ability to cope with the demand as insufficient. Given the interaction between the situation and the person’s perception of that situation, this notion has become integrated into what is known as the transactional model.

Park and Folkman (1997) extended these ideas, addressing the issue of meaning - what makes events or experiences meaningful in the context of stress and coping? They suggested that both global and situational meaning factors lead to appraisals and various coping strategies. Zakowski, Hall, Cousino-Klein, and Baum (2001) found that the coping strategies chosen by individuals tended to match their appraisals of stress controllability. Skinner and Brewer (2002) echoed these statements, asserting that viewing an event as challenging rather than threatening generally results in improved emotion-coping styles, positive feelings, and greater confidence. Janis (1983) examined medical patients prior to operations and found that those with moderate amounts of anticipatory anxiety, having appraised their pending operations as serious and concerning, had better medical outcomes than those with either much lower or much higher pre-operative anxiety. This suggests that what leads individuals toward successful psychological coping may not be blind optimism, but instead, a realistic appraisal of the situation.

There is some evidence that one’s selective attention shapes their appraisal. Zohar and Brandt (2002) found that the stressor perceived to be most salient captures the individual's attention and subsequently mediates how the individual appraises the situation. This is discussed further under the attention section of this report.

Matthews (2001) has developed an extensive model of driving performance, using a transactional concept of stress based on Lazarus and Folkman’s (1984) work. Matthews asserted that cognition plays two important roles in the mediation process between person and situation. The first role concerns the appraisal of the situation and second, the choice and regulation of coping strategies. Specifically, Matthews suggested three types of coping that are typically used by drivers performing under stressful conditions: 1) problem or task-focused coping - attempts to change the external reality of the situation, 2) emotion-focused coping - attempts to deal with the stressor through its reappraisal, and 3) avoidance coping - attempts to ignore the stressor through distraction. Other authors have concurred with this division of coping strategies (Hancock & Desmond, 2001; Weaver, Bowers, & Salas, 2001). For example, a driver might notice that he or she is driving at higher speeds than normal. This recognition may trigger an appraisal of one’s self as careless or reckless which in turn would lead to a task-focused coping response of speed reduction. This might also be accompanied by an emotion-focused coping response of reappraisal, justifying speeding because of being in a hurry or by having the skills necessary to handle the increased speeds. Another possibility is an avoidance coping response whereby one might turn up the car radio for distraction from further recognition of the speed. This would have the effect of both interrupting thinking and drowning out any subvocalization of concern.

Several investigators have demonstrated a relationship between appraisal and resulting stress or its amelioration (separate from performance degradation or enhancement). Abela and Alessadro (2002) confirmed the common perception that attitude was directly related to an individuals’ risk of developing depressive moods following negative events. Individuals whose attitude was positive, compared to those with more negative attitudes, were less likely to experience such negative affectivity following negative events. Endler, Speer, Johnson, and Flett (2001) found individuals’ ratings of self-efficacy, their perception of their own ability to affect change, was a better predictor of felt-anxiety than their perception of control over the stressful situation. Dandoy and Goldstein (1990) asserted that intellectualization, a cognitive tool used to emotionally distance oneself from a situation or feeling, was instrumental in positive coping (defined by a reduction in subjective distress ratings) both during and after viewing a threatening or disturbing video presentation.

Raggatt and Morrissey (1997) studied the effects of fatigue and stress on truck drivers. After measuring levels of arousal and anxiety during different stages in truck drivers' routes, they found that the expectation of the end of the shift resulted in a release in tension (although no performance decrements were noted). Slaven and Windle (1999) examined the effects of thermal stressors (extreme cold) on workers and found that the presence of peers raised motivation. They concluded that motivation was likely a mediating factor in improving perceptions of the worker's experience and that this resulted in sustained performance. From these and other studies it seems clear that effective cognitive coping often masks the conditions of high workload and stress.

Biological and Neurological Bases

Several authors have explored the biological bases for the appraisal system, specifically as it relates to the human stress response. Biondi and Picardi (1999) have provided the most thorough review of research examining the relationship between stress, cognitive appraisal, and neuroendocrine function. They found that one's subjective perception resulted in various psycho-endocrine response patterns, specifically, modulations among the pituitary-adrenocortical, adrenomedullary, and the sympathoneural systems. In general, the neuroendocrine system is believed to govern an organism's homeostatic state by regulating hormone secretion from the pituitary. The structure itself is located within the hypothalamus and consists of several subsystems, including the three mentioned above. These subsystems are believed to play a major role in the organism's adaptation to trauma and other stressful conditions (Selye, 1956) and previous research on humans and animals has shown that measures of these subsystems are sensitive to various indices of stress. Current neuroendocrine research suggests that during stressful conditions, the hypothalamus releases different types of hormones to either inhibit or stimulate the body's glands in order to perform various functions. The hypothalamus and pituitary regulate basic physiological functions such as heart rate, blood pressure, body temperature, and circadian sleep rhythms through the glandular release of stress hormones such as cortisol, dopamine, and norepinephrine.

Biondi and Picardi reported that mental arithmetic was perhaps the most commonly examined stressor among this literature and that it has been demonstrated repeatedly to induce elevations in plasma catecholamine levels such as epinephrine and norepinephrine. More specifically, their review of the literature suggested that these elevations resulted primarily from adrenal medulla and sympathetic nerve terminal releases. Mental arithmetic stress has frequently been paired sequentially with that of public speaking. This combination has been found to result in the addition of an adrenocortical activation (typically measured in salivary cortisol levels) as well. Similar results have been reported in Stroop color-word conflict examinations and under prolonged laboratory cognitive tasks. In fact, various investigations have shown that the more demanding the cognitive task, the greater the elevations of epinephrine and cortisol released. However, this pattern has not been observed among more pleasant emotional experiences. For example, under conditions of videogame playing, significant adrenomedullary activation does not occur, although some increases in norepinephrine have been measured.

Although there has been some concern over the generalizability of laboratory physiology findings to real-world experience (Dimsdale, 1984), Biondi and Picardi (1999) concluded that a consistent pattern of increased adrenaline, noradrenaline, and cortisol secretions have been found in both laboratory and naturalistic settings. In summarizing the findings associated with bereavement, these authors reported general agreement with the notion that adrenocortical activity is altered in many cases (i.e, increased levels of cortisol release). This appears to be the case particularly in instances where levels of anxiety and depression are greatest. Periods of student test and examination have also been studied and this literature also points to altered levels of catecholamines as is the case with research on the anticipation of surgical interventions. The nature of this change in catecholamine levels (whether it increases or decreases) interacts with the age of the subject and the chronicity of the stressor. In studies examining the immediate anxiety associated with parachute jumping, researchers have found a consistent pattern of an initial increase in cortisol levels as well as ACTH (adrenocorticotropic hormone) prior to the jump with an equal or greater release of adrenocortical activation following the jump.

According to Biondi and Picardi (1999) several lines of research have investigated the influence of coping strategies on hormone response. There is some data to support the notion that problem-focused interventions reduce psychoendocrine activity while avoidant or denial coping strategies actually tend to increase this response. The authors point out that these findings are modulated by the effectiveness of each strategy, implying that avoidant styles may in fact be less effective at dealing with stress than those that attempt to fix the problem directly. They concluded that these patterns appeared to suggest that one's appraisal is a, "main determinant of the psychoendocrine response…" (p. 139). Ennis, Kelly, Wingo, and Lambert (2001) also examined neuroendocrine activity and its relationship to cognitive appraisal. They determined that the sympathetic neuroendocrine system (measured in urine) increased differentially in individuals who perceived a test as threatening compared to those who viewed it as a challenge.

Leino, Leppaluoto, Ruokonen, and Kuronen (1999a; 1999b) studied psychophysiological stress reactions under high workload flying conditions. Their investigations supported an inverted-U relationship between neuroendocrine (adrenocorticotropic hormone-ACTH) function and mental workload, "A certain level of neuroendocrine activation in response to a psychological workload evidently increases a pilot's ability to perform….However, very high anticipatory levels of ACTH have been shown to correlate negatively with psychomotor performance." (1999a, p. 565). Their results indicated that plasma ACTH increased prior to (anticipatory stress reaction) and immediately after the IFR (instrument flight rules) flight simulation and these increases correlated significantly with performance on psychological tests. Plasma prolactin also increased following the flight, but not prior to it. This may suggest that prolactin is better suited as a neuroendocrine stress measure than ACTH (since it did not have an anticipatory stress function). Poor performance on the IFR simulation correlated with high plasma adrenaline immediately following the flight. Moreover, these authors also found that "subjects who have a higher need to perform well are likely to have higher neuroendocrine activation." (1999b, p. 575). This was also true of subjects who were rated as emotionally sensitive. The authors proposed that neuroendocrine activity following high workload could be used as a personnel selection tool, predicting stress reactivity and tolerance.

Bohnen, Nicholson, Sulon, and Jolles (1991) investigated whether salivary cortisol secretion, as an index of stress on mental task performance, reflected individual differences in coping styles. Their findings suggested that cortisol levels were in fact a useful index of subjective stress and coping strategy. Furthermore, these authors determined that using cognitive affirmations and cognitive reframing strategies was useful in the reduction of cortisol levels as well as corresponding subjective distress ratings. Other physiological dimensions have been studied in their relationship to performance and stress as well. Characteristics such as respiration or heart rate, muscle tension, perspiration, and skin temperature are quite common in this regard. This is likely due to 1) the fact that self-report measures have been criticized for their subjectivity, 2) the ease in measuring basic physiological markers, and 3) the historic relationship between stress, performance, and arousal theory.

The relationship between perceived threat and physiological reactivity has been examined using a number of real-world stressors. Rachman (1983) found significant physiological changes such as: increased heartbeat, labored breathing, and trembling while studying performance under the stress of bomb disposal. These symptoms tend to be highly correlated with the subjective experience of anxiety and fear. As one might imagine, positive performance expectations correlated with little fear and anxiety during such operations. Villoldo and Tarno (1984) replicated these findings. Under stress conditions of perceived threat, bomb disposal personnel committed a greater number of errors in operational procedures than when under non-stressful conditions. After an examination of novice and expert parachutists, MacDonald and Labuc (1982) found similar performance effects. Decrements among all phases of training and across multiple domains (logical reasoning; tracking and visual search tasks, decoding map references, etc.) were found as a result of perceived threat. Burke (1980) noted related decrements among Army jumpmaster trainees that perceived their parachute jumps as threatening as compared to those who did not. Rohrmann, Hennig, and Netter (1999) noted that subjects experiencing the stress of public speaking became more physiologically aroused when their stress was increased (being told that their heart rate was very high) as well as when they were reassured (told that their heart rate was relaxed). It was concluded that feedback of any kind tends to raise arousal levels because it requires cognitive processing that may interfere with internal coping strategies. It was also suggested that subjects may become frustrated when they are told they are relaxed when in fact they feel they are not.

In a classic study during W.W.II., Reid (1948) examined calculation and plotting errors in measuring wind vectors by navigators on operational sorties. He determined that error rates increased significantly when bombers crossed into enemy territory, and continued to increase as they approached their primary targets. These same error types decreased again on their return journey. Larsson (1989) investigated performance on an Army field artillery simulator, finding those that appraised the task to be challenging rather than threatening performed better. It seems likely that cognitive appraisal and subsequent felt-anxiety were the essential contributing factors among these investigations.

Predictability and Controllability

Integrally related to the previous discussion of cognitive appraisal and its effect on human performance under stress is the predictability or controllability of the stressor. In many ways, this dimension is nothing more than a special case of cognitive appraisal. In general, as would be expected, the more a situation or stressor is perceived as within one's control, the less stress provoking it appears to be. Similarly, the more predictable a negative event or set of circumstances is, the less distress it causes. While this has not been universally accepted (Averill & Rosenn, 1972; Staub, Tursky, & Swartz, 1971), in general, both control and predictability appear to be related to subjective distress and in many cases, overall performance as well.

Driskell, Mullen, Johnson, Hughes, and Batchelor (1992) described the nature and theory of controllability and defined it as the belief that one has at one's disposal a response that can influence the aversiveness of an event. These authors distinguished between behavioral control—the belief that a response can influence the aversiveness of the event, and cognitive control—the belief that a thought response can lessen the aversiveness of the event. Both are critical to an understanding of how appraisal works and each is tied to the two central coping strategies discussed previously, namely problem-focused coping and emotion-focused coping (Thompson, 1981).

The psychological stress associated with the threat of electric shock can be reduced when an individual perceives control over that shock (i.e., through behavioral decision making or performance; Bowers, 1968). Similarly, individuals report experiencing less anticipatory anxiety (Champion, 1950; Houston, 1972) and a corresponding decrease in physiological arousal (Geer, Davidson, & Gatchel, 1970; Szpiler & Epstein, 1976) pending this shock when it is believed to be controlled.

Threats due to crowding have been found to diminish when crowding was perceived as controllable by the individual (Baum & Paulus, 1987; Epstein, 1982). Similarly, the psychological stress and frustration associated with heat is reduced by the perception of controllability (Belle & Greene, 1982) as is the stress of perceived environmental toxins (Evans & Jacobs, 1982). Friedland, Keinan, and Regev (1992) asserted that stress results in an internal focus to endogenous cognitive processes (i.e., anxiety-related thoughts). They found that the perception of control over such stressors helped to regulate their subject's emotional responses.

The ability to exert control is clearly related to the ability to predict, and one could argue that predictability is a prerequisite of controllability. That is to say, if one can control an event's occurrence, they certainly can also predict it (the inverse is not necessarily the case). Several authors have found evidence that threatening stimuli that are predictable in some way (i.e., a warning signal) are less aversive than similar stressors that are unpredictable or unsignaled (Monat, Averill, & Lazarus, 1972; Weinberg & Levine, 1980). This has been demonstrated for the threat of electric shock (Badia & Culbertson, 1970; D'Amato & Gumenik, 1970) and sudden bursts of noise (Burger & Arkin, 1980).

In addition to a reduction in distress, performance outcomes have also been directly connected to perceived predictability and controllability. For example, Cohen (1978) suggested that the ability to predict stressors resulted in lower scanning behavior which in turn reduced task saturation and improved performance. Burger and Arkin (1980) found that uncontrollable bursts of noise increased errors on a free recall task, while Cohen and Weinstein (1981) studied random intermittent noise, finding similar decrements in performance. Salovey (1992) found that unexpected stressors in general tended to result in an attentional shift from external to internal processes. Thus, individuals exposed to unpredicted stress shifted their focus from what was happening to them to how they emotionally felt about the experience. Table 1 outlines various studies that have demonstrated the effect of cognitive appraisal systems on a range of performance outcomes.

Cognitive Appraisal and Attentional Bias

A large body of literature has evolved concluding that high-trait and high-state anxious individuals demonstrate an attentional bias toward threatening stimuli. This assertion rests on three theories: Beck (1976), who suggested that anxiety vulnerability relates to strong activation of schemas that are geared toward the processing of threat-related information: Bower's (1981), network theory proposed that a given emotional state leads to an activation of memory representations that are mood-congruent which in turn results in the selective processing of this information: MacLeod and Matthews (1988), suggested that such selective processing for threat-based cues occurs in high-trait anxious individuals under certain circumstances (possibly an interaction effect between trait and state anxiety).

Regardless of the theoretical underpinnings, the notion that anxious individuals show a bias toward emotionally threatening stimuli has been demonstrated repeatedly (Broadbent & Broadbent, 1988;

Calvo & Castillo, 2001; Mogg, Bradley, & Hallowell, 1994; Williams, Watts, MacLeod, & Mathews, 1988). In some instances this work has attempted to differentiate state from trait anxiety. Several investigations have supported the notion that individuals high on state anxiety measures tend to show such preferential processing (slower response rates to Stroop tasks; Mathews & MacLeod, 1985). Such findings suggest greater time is being taken to process threat-related information. Several researchers have concluded that these interference effects occur in subjects who are high in trait anxiety as well (Mogg, Matthews, & Weinman, 1989; Mogg, Matthews, Bird, & Macgregor-Morris, 1990; Pury & Mineka, 2001) while other investigations have found effects across both anxiety conditions (MacLeod & Mathews, 1988; Skosnik, Chatterton, Swisher, & Park, 2000). Egloff and Hock (2003) explored individuals' attention allocation toward threat-related stimuli through a comparison of the Stroop task and the attentional probe task. High-anxious individuals (as measured by the State-Trait Anxiety Inventory-STAI) showed an attentional bias toward threat words in each task (more time was spent attending to these words) while low-anxious individuals withdrew attentional resources in both tasks (less time was spent attending to these words). While overwhelming evidence supports the notion that anxious individuals show an attentional bias toward mood-congruent words or concepts, Fox (1993) found that under some circumstances state-anxious individuals actually shift their attention away from threat stimuli. While this is counter to previous findings, Fox believed this was an attempt to use a repressive coping strategy.

Hertel, Mathews, Peterson, and Kinter (2003) found that when non-anxious adults practiced a threat-related interpretation task (a semantic-judgment word task), threat-related interpretations transferred to an otherwise ambiguous word task that followed. Thus a threat-related interpretation of ambiguous words was induced in previously non-anxious subjects. The authors assert, "…across unrelated situations in the real-world, novel ambiguous cues invite interpretations congruent with previous understandings and consequently cause at least momentary increases in anxiety." (p. 783). Thus, individuals may demonstrate a tendency to both selectively encode threatening information but also apply a threat-based appraisal onto ambiguous stimuli as well.

Several researchers have explored the relationship between anxiety and cognition, asserting that anxiety-related appraisals significantly effect information processing. MacLeod (1996) stated, "…recent models of anxiety-linked performance deficits have placed increasing emphasis upon the possibility that the critical restriction in information processing capacity occurs centrally within the cognitive system, rather than resulting from a peripheral narrowing of attention." (p. 48). His suggestion is that anxiety creates deficits in cognitive performance by allocating mental resources toward task-irrelevant information that relates to the perceived threat, thus diverting these resources from the task at hand. Wofford and others (Wofford, 2001; Wofford & Goodwin, 2002; Wofford, Goodwin, & Daly, 1999) have consistently found that low-trait anxiety individuals were less prone to negative performance impact under stress as compared to high-trait anxious individuals (performance was measured across a variety of cognitive domains). However, such outcomes may be contingent upon various mediating factors. Stokes (1995) found that highly trait-anxious pilots showed decrements in performance only when they also were novices; expert pilots were not affected on an aeronautical decision making task by stress even when they scored as high-trait anxious.

Summary of Findings and Limitations to the Literature

Stress is a concept that we as a scientific community continue to struggle to define. With broad variations in descriptions the research literature in this area is often confusing and contradictory. For the better part of the last century research has relied on various theories to help explain the relationship between stress and performance. These include arousal, activation, energetical, and resource models. Each has struggled with its own limitations and the result has been a research community that is factional and disconnected. The lack of agreement between researchers has presented additional difficulties in unifying the literature. Furthermore, without an overarching theory to draw these elements together, there can be neither hope for a unitary explanation of mechanisms nor a sense of cohesion among concepts. This review reflects these disconnects within the research community while attempting to coordinate the extant body of diverse material. For the sake of simplicity and coherence, I have selected a definition proposed by McGrath (1976) that seems to be broad enough to incorporate most of the current assumptions about what stress is and is not, yet focused enough to be meaningful. McGrath conceptualized stress as the interaction between three elements: perceived demand, perceived ability to cope, and the perception of the importance of being able to cope with the demand. Unlike many previous definitions of stress, this formulation distinctly incorporates the transactional process believed to be central to current cognitive appraisal theories.

Transactional models that incorporate cognitive appraisal as a necessary element in human performance and information processing are the norm, and no longer the exception, in understanding the human stress response. Evaluations of threat, controllability, and predictability are central to cognitive appraisal and one's experience of subjective distress. In general, appraisal affects performance the way we might expect it would—negative evaluation often leads to negative outcome while positive evaluation appears to improve task performance (it reduces subjective distress as well as objective performance). How this process occurs, remains somewhat vague; however, there is gaining consensus that implicates an initial early evaluative function followed by a more involved higher-order cognitive process. The main purpose of this initial evaluation appears to be a preparatory one, facilitating the quick orientation and organization of the individual's response to the stimulus.

There continues to be debate within the research community regarding direct and indirect stress effects. Direct effects being those incurred by the task load alone irrespective of any psychological stress that may also be generated while indirect stress effects are those that evolve out of psychological factors associated with the task load demands. Clearly there is a fine line that separates these two, and they can be indistinguishable at times. Researchers have been inconsistent in their treatment of this issue, equating them in some instances and differentiating them in others. Although it can be argued that each stressor involves direct effects, each can also carry indirect effects as well. For example, time pressure limits the time available to perform a given task. This limit is a physical boundary that does not require any psychological explanation in understanding its direct effects on performance. However, this limitation often evokes a corresponding psychological reaction such as anxiety that has secondary or indirect effects on performance. Given the difficulty in separating these two dimensions and the rarity in which this has been done in the primary literature, I have simply tried to make the reader aware of the issue and have not attempted to separate them in this review.

Research has also explored the relationship between biological and neuro-anatomical elements and cognitive appraisal. This research has found that one's subjective perception results in various psycho-endocrine response patterns, specifically, modulations among the pituitary-adrenocortical, adrenomedullary, and the sympathoneural systems.

Finally, the notion that anxious individuals show a bias toward emotionally threatening stimuli has been demonstrated repeatedly. Attentional biases toward such stimuli have been found in state and trait anxious subjects. Moreover, there is a robust clinical literature supporting the suggestion that anxious individuals (state, trait, or disordered) may experience a greater difficulty avoiding encoding threatening stimuli than non-anxious individuals. This literature is largely based on the work of Beck (1976; Beck, 1987) and those among the dominant theoretical schools of cognitive-behavioral psychotherapy. However, due to the limited scope of this review—primarily focusing on non-clinical populations and addressing acute stressors—a review of this literature is not provided here.

Several caveats to the preceding review should be considered. The overwhelming majority of research studies mentioned above consisted of laboratory paradigms. In some cases, particularly among the cognitive appraisal literature, there are real-world findings consistent with those established experimentally and posited theoretically. However, such studies are rare among research examining the effect of predictability and controllability on performance and even more so on research investigating attentional bias. These issues are discussed further in a later section of this report. Appendix A describes the cognitive appraisal component of this review's information processing framework.

Table 3. Cognitive Appraisal and Performance Enhancement.

Source	Stress or Task	Measurement	Performance Outcome
Burger & Arkin (1980)	Free recall memory task	Perceived uncontrollability of noise	Greater number of memory errors
Burke (1980)	Parachuting	Perceived threat	Performance decrements
Cohen (1978)	Visual scanning	Ability to predict stress	Reduced task saturation & improved performance
Cohen & Weinstein (1981)	Free recall memory task	Perceived uncontrollability of noise	Greater number of memory errors
Larsson (1989)	Artillery simulation	Perceived threat	Performance decrements
MacDonald & Lubuc (1982)	Parachuting	Perceived threat	Logical reasoning, visual tracking, search, & map decoding decrements
Rachman (1983)	Bomb disposal	Physiological arousal, anxiety & fear	Formed negative perceptions of their performance
Reid (1945)	Aerial navigation under combat		Greater number of calculation & plotting errors
Rohrmann, Hennig, & Netter (1999)	Public speaking & feedback	Physiological arousal	Information processing interference
Villoldo & Tarno (1984)	Bomb disposal	Physiological arousal	Greater number of procedural errors

The Effect of Stress on Attention

In previous sections, attention and its role in resource allocation as well as its selectivity have already been partially described. In the following discussion, I will review various findings regarding the effects of stress and workload on attention.

In general, under stress, attention appears to channel or tunnel, reducing focus on peripheral information and tasks and centralizing focus on main tasks. What determines a main task from a peripheral task appears to depend on whichever stimulus is perceived to be of greatest importance to the individual or that which is perceived as most salient. Threat-relevance is believed to be strongly associated with salience. Therefore, when environmental cues are threat-related, such stimuli are often considered to be most salient by the individual. As one can imagine, this tunneling of attention can result in either enhanced performance or reduced performance, depending on the nature of the task and the situation. For instance, when peripheral cues are irrelevant to task completion the ability to tune them out is likely to improve performance. On the other hand, when these peripheral cues are related to the task and their incorporation would otherwise facilitate success on the task, performance suffers when they are unattended.

Pre-Attentive Processing and the Orienting Reflex

Attentional processing is preceded by an initial orientation to the stimuli. This initial orienting response occurs immediately and without volition. Rohrbaugh (1984) described the orienting reflex as involuntary, immediate, and nonspecific. He suggested that this response was typically elicited from stimuli that are novel or intrinsically salient. Rohrbaugh mentions that William James (1890) provided a very similar observation over 100 years ago. In fact, there is a long and distinguished history of research concerning the orienting reflex in the field of psychology. The earliest experimental work was conducted by Pavlov (1927), and this work was expanded significantly by many others (Kimmel, Van Olst, & Orlebeke, 1979; Lynn, 1966; Sokolov, 1963; Van Olst, 1971).

According to Sokolov's model, once a given stimulus is detected, it enters into a pattern recognition system through which it is compared to a pre-existing "library of internal representations (neuronal models) of previous stimulations." (p. 324). Rohrbaugh viewed the significance and general purpose of the orienting reflex as preparatory to future stimulus perception. It seems likely that this process is related to the evaluative reflex that has been argued to occur prior to higher-order cognitive appraisal (Duckworth et al., 2002) and may in fact be a preparatory step that primes the organism for further evaluation and, eventually, responsive action.

In their examination of the relationship between emotion and attentional processing, Ohman, Flykt, and Esteves (2001) differentiated between active and passive attention. The former refers to a top-down processing while the latter suggests a bottom-up, stimulus-driven process. Top-down processing implies a volitional search and organism-directed attentional processing while bottom-up processing involves cues in the environment that draw-in attention. In their review of this literature, these authors discuss the distinction between preattentive (automatic, parallel processed) and postattentive attention, that which is deliberate and serially processed. They noted that several authors have previously reported a "pop-out" effect in preattentive detection of threat stimuli (Ohman, 1993; Treisman, 1988). Complimenting the work of Duckworth and colleagues (2002) and others, Ohman, Lundquist, and Esteves (2001) found attentive detection biases toward angry faces over happy, sad, and affectively neutral faces. These authors suggest a psychophysiological preference that may be linked to the evolutionary significance of a stimulus.

Working from a bio-evolutionary model, Ohman and colleagues (2001) explored the role of automatic processing of fear-relevant stimuli among visual displays that varied in complexity. These authors used two fear-relevant and two fear-irrelevant stimuli. In the first category, images of snakes and spiders were employed while the second category relied on flowers and mushrooms. Subjects were asked to detect discrepancies between matrices of pictures that either contained all the same stimuli (all mushrooms) or the same with a discrepant target (a snake among the mushrooms). The researchers hypothesized that subjects would be quicker to detect discrepant images when they were fear-relevant as compared to fear-irrelevant. Such findings would support the notion that fear or threat-relevance may enhance the saliency of an object, resulting in attentional control and processing. The results of their first experiment showed that subjects were faster in their detection of fear-relevant stimuli. Furthermore, subjects were fastest when these targets were located toward the middle of their visual fields. Upon closer examination, it became clear that this effect was greatest when fear-relevant stimuli were present. However, under fear-irrelevant stimulus conditions, subjects tended to implement a systematic search pattern, unlike the central-features scan relied on under fear-relevant conditions. In order to further test the "pop-out" effect found in their initial experiment, Ohman and colleagues (2001) conducted a second experiment increasing the size of the pictoral matrix (presumably increasing its visual complexity). The results of the second experiment were similar to those reported earlier. Reaction times did increase as complexity of the visual display increased. Subjects were found to detect fear-relevant stimuli faster but also removed their attention from these stimuli more quickly in their detection tasks. Ohman and colleagues suggested that this finding may reflect an attentional control mechanism that is aligned with an evolutionary response to the presence of threat.

The authors acknowledged that the saliency of the stimuli may have resulted in the subject's preferential attention and not the object's fear-relevance per se. In one further exploration, these authors examined the role of fear perceptions on attentional processing. After distinguishing between fearful and nonfearful subjects through self-report, subjects were once again exposed to the experimental conditions as prescribed by the first two experiments. The results of the third investigation confirmed the previous two and found that subjects who reported being fearful of snakes and/or spiders were faster than those who were nonfearful in detecting these target stimuli. Detection latencies were briefer for both groups when responding to fear-relevant images. These findings are certainly consistent with the previous literature concerning the attentional bias demonstrated by anxiety (Mogg, Bradley, & Hallowell, 1994; Williams, Watts, MacLeod, & Mathews, 1988). The authors concluded that threat-based stimuli tend to be detected under preattentive processes that are automatic and processed in parallel. Stimuli that are not threat-based may be subject to more systematic postattentive processing strategies. Furthermore, Ohman et al. suggested that emotion, "…involves 'attention control settings' that make goal-relevant stimuli salient for the person." (p. 475). This observation further implicates goal structure and motivational influences in attentional resource management. This issue is discussed in greater detail later in this review.

Ohman et al.'s (2001) conclusions have not been universally accepted. Recent work by Ellenbogen, Schwartzman, Stewart, and Walker (2002) explored the relationship between stress and selective attention as it relates to mood and emotional information processing. They found that individuals under stress (a competitive computer task requiring spatial cueing and word recognition) did not selectively attend to negative stimuli when exposed to them, but instead rapidly disengaged attention from these negatively valenced words (and not from positive or neutral words). This was not the case for individuals scoring high on a self-report measure of dysphoric mood. The authors postulated that their finding may result from an adaptive strategy to regulate emotional arousal, particularly negative affectivity. Given the response time for this attentive withdrawal (est. 350ms) it may reflect a relatively automatic attention bias toward more positive stimuli for individuals who are not experiencing any negative affective state (see previous discussion of Fox, 1993).

The Tunnel Hypothesis

The greatest effect found in the research literature concerning attentive processes under stress occurs after these initial stages of orienting and evaluating. The majority of the field has converged on the notion that stress and workload reduce cue utilization, shrink the perceptive field, or reduce an individual's environmental scan. Much of this perspective has reverberated from Easterbrook's (1959) article that demonstrated the relationship between motivation, drive, arousal, and cue utilization, ultimately concluding that there was a restriction in the range of cues attended to under stress conditions. This tunneling hypothesis has been echoed by numerous investigators (Baron, 1986; Broadbent, 1958, 1971; Bundesen, 1990; Bursill, 1958; Cohen, 1980; Combs & Taylor, 1952; Cowan, 1999; Davis, 1948; Driskell, Salas, & Johnston, 1999; Hockey, 1970; Hockey, 1978; Hockey & Hamilton, 1970; James, 1890; Murata, 2004; Pamperin & Wickens, 1987; Salas, Driskell, & Hughes, 1996; Stokes, Wickens, & Kite, 1990; Vroom, 1964; Wickens, 1984; Williams, Tonymon, & Anderson, 1990; Zhang, 1989).

Years prior to Easterbrook's seminal work, Kohn (1954) addressed the effects of stress on aspects of perception and performance. Specifically, he postulated that intense emotion disorganizes perceptual relationships, "Under conditions of stress…the perceptual field is constricted or narrowed, and the scope or span of behavior tends to be restricted to those elements which contribute most to the direction of behavior, or to those elements which appear to be the most threatening." (p. 290). Kohn (1954) conducted two experiments using threat of electric shock on social-perception comprehension (comic strip analysis) and story comprehension and recall. The results of this study found that recall and analysis of details were worse under emotional conditions than under those of low or no threat. In addition, he found that recall tended to be selective for main features over peripheral details. This outcome seems likely to be related to previous selective attention rather than necessarily a direct effect on memory, although this was not examined by the author.

Kohn (1954) observed that subjects appeared to realize that the threat of shock disrupted their concentration on tasks. The author also commented on the cyclical nature of evaluation or appraisal and its affective response, "A vicious circle may be effected such that the perception of a poor performance results in an emotional experience, which acts to further decrease the efficiency of performance. Perception of this performance decrement then again increases emotional intensity…Emotion, then, is the conscious correlate of the person's perception of the stresses and the strains of the environment, and his perception of his reactions." (p. 301).

Callaway and his colleagues (Callaway & Dembo, 1958; Callaway & Thompson, 1953) also studied the effect of stress on attention and found a narrowing of attentional processing under emotional states such as anxiety. Callaway and Dembo (1958) tested the visual judgment of sizes of objects by subjects exposed to one of two different conditions. One group was asked to inhale amyl nitrite. This substance, now known as the street drug "rush," produces a "high" that lasts from a few seconds to several minutes. The immediate effects include decreased blood pressure, followed by an increased heart rate, flushed face and neck, dizziness, and headache. The purpose of this exposure was to examine the effects of various physiological changes in visual perception. The second group of subjects was instructed to put their foot into a bucket of ice water simulating stressful conditions related to thermal discomfort.

The authors found that subjects of both groups tended to judge the objects as larger than controls. Due to the fact that size judgments typically require the incorporation of peripheral cues such as elements in the foreground (shadow, texture, relative position of other objects, etc.) the authors concluded that subjects had not attended to these cues, focusing instead on the central object. These judgments did not appear to be related to ophthalmic changes, and Callaway and Dembo (1958) surmised that some physiological mechanism seemed to increase the selectivity of an individual's attention. These effects were then replicated using epinephrine and methamphetamine injections (Callaway, 1959). Interestingly, in yet another examination of the pharmacological effect on attentional processes, Callaway (1959) found that amorbarbital tended to widen attention. Amorbarbital is classified as a sedative-hypnotic drug and typically causes a slowing down, or depression, of the central nervous system. At low doses, these drugs produce a feeling of calm, drowsiness, and well-being. The author asserted that the physiological mechanism at work may lie within the reticular activating system and relate to organism alertness. In total, he and his colleagues found narrowed attention effects in size matching, muscle response, skin response, and various guessing behaviors as a result of their manipulation of stress conditions.

Baddeley (1972) supported the notion of attentional tunneling through numerous experiments primarily in real-world operational studies (i.e., underwater diving). He concluded, "danger affects performance…through its influence on an individual's breadth of attention." Furthermore, he conjectured that an "increase [in] level of arousal…will focus an individual's attention…on those aspects of the situation he considers most important." (p. 545). Interestingly, Baddeley found that experience mediated this effect. He asserted that it was due to an inhibition of anxiety in the dangerous situation, which thereby reduced the impairment on performance. These findings are discussed further in a later section concerning the effects of stress on perceptual-motor tasks.

Bacon (1974) induced arousal in subjects by the threat of electric shock and then judged their performance on a pursuit-rotor tracking task. His results tended to support Easterbrook's hypothesis. Bacon indicated that the restricted range attended to by subjects may or may not reflect an enhancement toward central cue perception, but that it did appear to reduce the processing of peripheral cues. Bacon went on to assert that this restriction in attention likely leads to a disruption in memory as well. Not all authors agree with this later assertion. Eysenck and his colleague (Eysenck, 1979; 1985; Eysenk & Calvo, 1992) have suggested instead, that anxiety caused by a stressor results in task-irrelevant cognitions leading to resource allocation that is diverted from working memory processes. A similar argument has been posited by Friedland, Keinan, and Regev (1992). In addition to the effects on memory, they have asserted that stress also narrows attention, turning one's focus to internal distress and endogenous cognitive processes. They found that the perception of control over such stressors helped to regulate their subject's affective responses. MacLeod (1996) has also argued the merits of a direct effect on information processing capability versus an indirect effect via attention.

Several authors have explored the effect of noise on attention and found results consistent with the attention tunneling hypothesis (Broadbent, 1978; Houston, 1969). Broadbent provided an extensive literature review concerning the effects of noise on attentional processing (mostly signal detection and sustained attention tasks in laboratory paradigms). Broadbent identified three deficits resulting from noise exposure: 1) reduction in signal detection, 2) increase in inefficient performance leading to increases in error rates, and 3) selective attention (focusing on some aspects of an object while neglecting others). Diaz, Hancock, and Sims (2002) reported a speed/accuracy trade-off, reducing the effectiveness of visual search under noise conditions. Houston (1969) found an increase in noise resulted in centralized focus that improved performance on the Stroop color-word task while limiting attention to peripheral cues. The Stroop task or one of its variations is perhaps the most widely used test for the assessment of attentional interference (MacLeod, 1991). Although there are a number of derivations of the Stroop, traditionally this paradigm incorporates a list of color words (i.e., red, blue, green) that are printed in colored ink. The subjects are asked to name the print color, ignoring the word itself (i.e., the word red might appear in blue ink). There are cases in which the word names its color and others in which it does not. The Stroop effect occurs when there is a difference in performance on congruent versus incongruent elements; specifically, when the word interferes with the naming of its color. On the other hand, the reverse Stroop effect occurs when the color of the word interferes with the naming of the word.

However, not all researchers have reported such robust and directional findings. Lavine, Sibert, Gokturk, and Dickens (2002) found that performance on a sustained-attention task requiring signal detection and visual scanning decreased as a function of time on task. Conditions of 50 dB of white noise appeared to contribute to ratings of fatigue and decrements in visual scan (less dwell time and fewer on-target fixations) and an overall performance on the task; however, when subjects were exposed to unpredictable bursts of 90 dB of noise, performance improved. The authors suggested that this may have been due to increased alertness and attention following the noise bursts. Coates and Alluisi (1975), after exposing subjects to the stress of noise, failed to find any decrement in vigilance performance. Furthermore, Kirk and Hecht (1963) also found that variable noise facilitated vigilance performance. Murata (2004) examined the effects of workload (measured by foveal task complexity) on the human visual field. Using an addition task with varying degrees of difficulty, he tested the findings of previous investigations (Bursill, 1958; Mackworth, 1965) that suggested increased workload would result in a reduction of the functional visual field (the information processed around a fixation point that is later used in recollective processes). Murata's investigations revealed mixed results (both in support of previous findings and in conflict with these findings).

Hancock and Weaver (2002) and others (Hancock, Szalma, & Weaver, 2002) have argued that phenomenologically people report experiencing a time distortion under stress. The conclusions of these authors suggest that stress does cause a reduction in environmental sampling and that this results in distortions in the perception of space and time. These findings are consistent with those asserted by Callaway and Dembo (1958) reported earlier.

Several groups have studied the effects of time pressure on attentional processes. Entin and Serfaty (1990) examined the decision-making of military personnel under the stress of time pressure in a combat simulation study. Their results suggested a reduction in the frequency and/or amount of information sought by decision makers as well as a reduction in the accurate detection of friend or foe submarines under high-stress conditions. Ozel (2001) examined how people process environmental information for exiting (fire fighting scenarios) under time pressure and the stress and threat of fire. Based on the existing research literature, Ozel theorized that when slightly stressed, one's ability to determine the best time to exit was likely to be enhanced while under high levels of stress there would probably be a restriction in the range of cues attended to and a distortion of information processing. He asserted that the result was likely to be a decrement in performance.

In addition to the general finding that various stressors appear to result in a tunneling of attentional processes, several studies support the idea that attentional tunneling can be reproduced and reversed pharmacologically. Caldwell and his colleagues (2001; Caldwell & Caldwell, 1997; Caldwell & Gilreath, 2002) have examined this line of research extensively. Caldwell and Gilreath (2002) surveyed U.S. Army aviation personnel and clearly demonstrated the widespread prevalence of fatigue factors and related stressors in the military aviation community. While Caldwell (1997) addressed these factors and detailed the numerous countermeasures currently available to those in aviation, Caldwell and Caldwell (1997) focused their investigation on the use of various pharmacological agents in stimulating the very cognitive functions compromised by fatigue and associated stressors. For instance, performance on several flight measures was enhanced after the introduction of dextroamphetamine (Dexedrine R): airspeed, heading, roll, and turning control. Furthermore, self ratings of mood and physiologic measures of alertness and attention (predominantly arousal measured by EEG) also improved with pharmacological intervention. Similar findings have been obtained by the use of modafinil (Provigil R). This is certainly not a new assertion and many researchers have reported such findings in military aviation. For example, dextroamphetamine has been used in sustained and continuous flying operations in the military with significant success in the past (Cornum, 1992; Emonson & Vanderbeek, 1995; Senechal, 1988).

Table 4 outlines research studies supporting the attention tunneling hypothesis and lists the conditions of study.

Table 4. Studies in support of the Tunnel hypothesis.

Source	Stress Manipulation	Task	Setting
Bacon (1974)	Electric shock	Pursuit-rotor tracking	Laboratory
Braunstein-Bercovitz, Dimentman-Ashkenazi, & Lubow (2001)	Threat to self-esteem	Mathematical calculations	Laboratory
Broadbent (1978)	Noise	Various tasks	Review
Callaway (1959)	Pharmacological	Visual judgment of size	Laboratory
Callaway & Dembo (1958)	Pharmacological & Discomfort of cold	Visual judgment of size	Laboratory
Chajut & Algom (2003)	Threats to ego, Time pressure, Task difficulty, & Noise	Stroop & reverse Stroop	Laboratory
Entin & Serfaty (1990)	Time pressure		Visual identification
Simulation			
Kohn (1954)	Electric shock	Social-perception & story comprehension with recall	Laboratory
Hockey (1978)	Noise	Various tasks	Review
Hockey (1979)	Stress	Sustained attention &	Review

		memory	
Houston (1969)	Noise	Stroop	Laboratory
Houston & Jones (1967)	Noise	Stroop	Laboratory
Lavine, Sibert, Gokturk, & Dickens (2002)	Noise	Vigilance task	Laboratory
Ozel (2001)	Fire & Time pressure	Decision to leave a fire	Real-world
Recarte & Nunes (2000; 2003)	Mental workload	Driving task & visual search discrimination	Simulation
Zhang (1989)	Workload & Noise	Visual displays	Laboratory

Vigilance and Sustained Attention

William Shakespeare's play, *The Tempest, Act 3, Scene 3*, includes the line "For now they are oppress'd with travel, they will not, nor cannot, use such vigilance as when they are fresh." (quoted in Mackworth, 1948). Perhaps the most common form of attentional processes examined in stress research is that of vigilance or sustained-attention. Mackworth (1948) explored vigilance performance employing several experiments that required prolonged visual search. In doing so, he attempted to resolve an age-old controversy over the effect of stress and sustained attention tasks. Various authors had waged debate whether the stress of sustained-attention affects the efficiency and performance of vigilance or just one's mood and feeling states. He noted that this debate was argued vociferously during the first half of the twentieth century. Mackworth proposed that the stress associated with vigilance tasks was the result of, "undue prolongation of the task itself." (p. 6). Moreover, he felt that vigilance was a useful concept in describing the psychological readiness of the organism. In his own investigation, Macworth used a clock test, requiring subjects to sustain their attention to a rotating arm of the clock. He examined Royal Air Force cadets for different lengths of time under two conditions (interruption of the task via a telephone call and no interruption). Decrements in vigilance were found when the clock test was prolonged beyond thirty minutes, when subjects had recently responded to a signal (movement in the rotating arm of the clock) and were not expecting another, and when they expected an auditory stimulus while doing the visual task. Performance improved when a short rest of thirty minutes was provided, when they were interrupted by a telephone call, when they were provided immediate feedback on their performance, and after taking 10mg of amphetamine sulphate prior to the task. Mackworth concluded that the efficiency in performance of the task was degraded not simply by the boredom of the task but instead, by the extinction of the subject's conditioned response (due to the diminished reinforcement provided by a loss of expectation). In other words, as the subjects in this study were no longer reinforced with the knowledge of their performance results (hearing "Yes" or "No" from the experimentor), they became less diligent in pressing the response key (when they heard the long signal tone). Temple, Warm, Dember, Jones, LaGrange, and Matthews (2000) also found significant decrements in performance after only thirty minutes of sustained attention and revealed that this period of vigilance was sufficient to increase subjects' perception of workload and stress.

Sustained attentional processes were examined by Scerbo (2001) as well. He suggested that vigilance performance under stress can result in both drops in accuracy and increases in response time. He found that subjects experienced greater stress after performing a vigilance task, finding the task itself stressful, as compared to an alternative kaleidoscope task. He noted that these subjects also experienced greater boredom when they could not terminate the task voluntarily. As a result, he postulated that subjects who can terminate a task at will, won't experience stress because they can quit prior to incurring any negative feelings. This assertion is in line with research that identifies controllability and cognitive appraisal at the heart of subjective distress. Further, the author found that subjects who were provided verbal instructions that emphasized the vigilance task (telling them to "pay attention"), rated their workload as higher and more stressful, than those who performed the same task without this emphasis. Thus, the stress associated with vigilance tasks may be related to the task demands themselves but also to the cognitive appraisal of boredom associated with these demands. Scerbo (2001) summarized, "…allowing individuals the freedom to terminate a task at will appears to be the only way to keep boredom in check. Increasing stimulus variety can prolong the time and individual is willing to work at the task, but it does not prevent boredom; it merely delays its onset." (p. 275).

The most commonly examined stressors applied to tasks of vigilance are, fatigue and sleep deprivation. Baranski, Gil, McLellan, Moroz, Buguet, and Radomski (2002) exposed subjects to 40 hours of sleep deprivation in an attempt to estimate the impact of fatigue on a host of cognitive performance factors. They found decrements equally distributed across all of the domains tested (i.e., serial response times, logical reasoning, visual comparison, math, vigilance, and multitasking). Similar results have been observed by others as well (Samel, Wegmann, Vejvoda, Drescher, Gundel, Manzey, & Wensel, 1997; Wilkinson, 1964; Williams, Lubin, & Goodnow, 1959). Several investigations have reported the effect of circadian rhythm desyncrony on performance. Blake (1967) found significant decrements in vigilance occurred under these conditions as did Colquhoun (1971). Whether or not these effects are due to stress per se (versus a more direct influence) can be debated. Fatigue's direct physiological effects are difficult to separate from its psychological effects. Research has shown that the direct effects of various stressors (to include fatigue) can be modulated by individual differences and psychological processes (i.e., motivation, effort, etc.). In almost all of the investigations included in this review, the researchers fail to discuss this matter, let alone attempt to distinguish between the two, within their experimental designs.

In their review of the literature on stress and performance, Davies and Tune (1970) indicated that vigilance tended to be enhanced by moderate levels of arousal; however, sustained attention appeared to decrease with fatigue and loss of sleep. These authors reported that noise research showed mixed results, with noise enhancing complex tasks but worsening simple tasks. Kjellberg (1990) also examined the effect of noise (moderate intensity) on vigilance. He found that workers reported experiencing distraction and sleep disturbances due to such exposure and he observed decrements across attention tasks as well as decreases in reaction times and performance on verbal comprehension tasks. Noise and fatigue are not the only "stressors" implicated in vigilance decrements. Pepler (1958) also found that exposure to heat resulted in diminished vigilance. Van Galen and van Huygevoort (2000) found that time pressure and workload resulted in more errors, greater movement variability and greater cursor control pressure on tracking and vigilance tasks. Wickens, Stokes, Barnett, and Hyman (1991) found that under time pressure, noise, and financial risk, individuals performed more poorly on tasks of vigilance and attention; however, declarative knowledge tasks were not affected.

Several researchers have argued that stress leads to hypervigilance, a state of disorganized and somewhat haphazard attentional processing, that tends to degrade judgment and decision making skills (Janis & Mann, 1977). This has been found to be true for some decision making tasks that come under the stress of perceived threat (Janis, Defares, & Grossman, 1983). Keinan (1987) reported similar results. Keinan had subjects perform a multiple-choice analogies test to assess the range of alternatives they considered prior to making a decision under the threat of electric shock. He noted that when individuals felt threatened they tended to abandon organized and systematic scan patterns, they examined fewer alternatives, and their examination of options was less systematic than those who did not feel threatened. This reduction in scanning for alternatives affected their decision making negatively.

Attentional Workload and Resource Allocation

Attention has been measured a variety of ways in the research literature; however, most often it is a subject's visual scan and their detection of various objects within their perceptual field, that have been used to determine attentional workload. In terms of vigilance research, various authors have suggested that the vigilance task itself, without the addition of an external stressor, is considered stressful by subjects (Frankenhaueser, Nordheden, Myrsten, & Post, 1971; Galinsky, Rosa, Warm, & Dember, 1993; Hancock & Warm, 1989; Hovanitz, Chin, & Warm, 1989; Scerbo, 2001; Warm, Dember, & Parasumraman, 1991). Subjects have rated both visual and auditory vigilance tasks as stressful, although auditory attention was rarely examined. It seems likely that these ratings reflect the direct influence of mental workload associated with the task.

Hughes and Cole (1986) explored attentional workload associated with driving a car. They found that under non-stress conditions driver's attention was focused on objects unrelated to the driving task 30-50% of the time. This was compared to rates established by Renge (1980) who found only about 20-25% of such "spare capacity" being spent on task-irrelevant activites. Suzuki, Nakamura, and Ogasawara (1966) reported that 50% of the time, fixation was directed on objects unrelated to the driving task while 15-20% of attention (per verbal report) was spent on road traffic control devices. Renge (1980) found a similar proportion (18-23%). Hughes (1989) has also observed that as the visual complexity and number of visual stimuli increased during driving, subjects adapted their visual gaze frequency and fixation (reducing the duration of their glances). This finding may provide some descriptive evidence of how drivers shed tasks when cognitively overloaded. It should be pointed out that these results are not universal across the research literature (Rockwell, 1988), but do reflect most findings.

Lansdown (2001) explored driver visual workload and argued that visual inputs are the primary source of information for drivers. Sabey and Staughton (1975) estimated that over 90% of information received while driving is visual and thus combating this system's potential overload is paramount in preventing accidents (Wall, 1992). Lansdown differentiated performance of novice and expert drivers citing that experts tended to be more efficient in their attentive processing. Specifically the author cited that experts relied more on peripheral visual cues to maintain lane position as compared to novices who relied heavily on foveal fixations. This finding led the author to suggest that experts have more attentional resources to devote to other events or situations than novices. Such a suggestion is clearly supported by other research on differences in resource management by experts versus novices (Burke, 1980; MacDonald & Lubac, 1982; Stokes, 1995).

Matthews and Desmond (1995) posited that within the context of driving abilities and use of automation systems, stress tends to have three effects: it overloads attentional capacity, disrupts executive control over selective attention, and disrupts adaptive mobilization of effort. Metzger and

Parasuraman (2001) found this to be true in their examination of driving behavior under increased attentional workload. Matthews, Sparkes, and Bygraves (1996) also studied driving performance under various conditions of stress (increased workload via a grammatical reasoning task using both visual and auditory inputs). In this instance, drivers adapted to higher levels of demand efficiently. This finding is contrary to the authors' dual-task interference prediction and the attention-resource theory that has otherwise found widespread support. Recarte and Nunes (2000; 2003) examined the effects of mental workload on visual search and decision making in a simulated driving task. They conceived of the subject's tasks as one of divided attention between the driving task itself, visual search discrimination and other cognitive tasks. Using pupil size as a measure of mental load, these investigators found that increases in workload during driving increased spatial gaze concentration; thus there was less scanning of non-central-features. Furthermore, mental load increased pupil size, indicating additional mental effort and spatial gaze concentration on the driving tasks. Mental task load resulted in internal distraction (one type of mental activity that disrupted another) affecting attentional capacity for visual stimuli as well as a reduction in the number of targets scanned.

Stress-induced cognitive tunneling or narrowing of attention has also been causally linked to airline accidents and crash sequences (Kornovich, 1992). Due to the high workload and inherent stressors associated with flying, the design of aviation systems has been a priority of various human factors engineers and cognitive scientists. Several authors have explored the relationship between HUD (head up display) symbology used in aircraft operations and attentive processes (Dowell, Foyle, Hooey, & Williams, 2002; Foyle, Dowell, & Hooey, 2001; Ververs & Wickens, 1998). The results of these investigations suggest that such symbology is so compelling that it fosters cognitive tunneling under the workload of flying. For instance, it has been found that pilots can fixate attention to HUD symbology, focusing on one source of information to the detriment of other sources. The result is a decrease in overall situational awareness and a greater vulnerability to error (Wickens, Fadden, Merwin, & Ververs, 1998). These authors have also suggested that various design modifications and compensatory strategies appear to be available to reduce this risk. For instance, in a similar investigation, Wilson, Hooey, Foyle, and Williams (2002) found that situation-guided symbology in HUDs led to increased situational awareness, increased taxi speeds, and less workload. They surmised that this was at least in part due to a reduction in cognitive tunneling. Automation and its role in simultaneously decreasing and increasing mental workload as well as error has a large and well-developed literature of its own and is beyond the scope of this review. The interested reader is referred to Mouloua, Deaton, and Hitt (2001) for an overview of these issues.

Beilock, Carr, MacMahon, and Starkes (2002) explored the effect of attention on sensorimotor skills. They found that well-learned skills do not require deliberate, conscious control of attention and as a result dual-task performance is easier. Given that well-learned skills tend to require fewer mental resources for their performance, more resources are available to devote to additional tasks accordingly. When prompted to focus attention to a particular component of the well-learned task, performance was degraded. It appears that the step-by-step attention to tasks is beneficial during initial learning stages but that this tends to be detrimental once skills are well-learned.

Braunstein-Bercovitz, Dimentman-Ashkenazi, and Lubow (2001) examined the effect of stress (threats to self esteem) on latent inhibition—the mechanism implicated in attentional processing that underlies the ability to separate relevant from irrelevant information. In traditional latent inhibition designs, subjects are first exposed to relevant and irrelevant stimuli. In subsequent trials these subjects are exposed to the same irrelevant stimuli along with a new set of novel stimuli. Subjects tend to take longer in processing the previously-exposed stimuli than they do the novel stimuli. This phenomenon has become known as the latent inhibition effect. Braunstein-Bercovitz and colleagues placed subjects under low-stress and high-stress conditions, defined by the difficulty of mathematical calculation tasks. Stress was further manipulated by indicating to the subjects that these tasks were highly correlated with general intelligence (these manipulations were validated by self-report). Those in the high-stress condition were provided very difficult problems including some that were unsolvable. Their results suggested that stress caused increases in state anxiety which affected selective attention caused by a disruption in attentional inhibition. This may suggest that subjects were unable to discern task irrelevant information from task relevant information. On the other hand, it may indicate that subjects' attention was simply drawn or directed toward task irrelevant information to the detriment of performance. These findings support the hypothesis that attentional resources are diverted to task irrelevant cues under conditions of stress and anxiety.

In an extension of these initial findings, Braunstein-Bercovitz (2003) attempted to further clarify the effects of stress on selective attention. Using two negative priming experiments, the author induced stress by threatening subject's self-esteem (difficult tasks purportedly measuring intelligence). Participants experienced a series of trials, each comprised of a pair of displays. Each display contained a prime followed by a probe. In the low-load condition, three digits appeared on the display screen, the middle was identified as the target stimulus while the two identical digits flanking the target were considered distractors (to be ignored). Conditions were similar under the high-load displays (although using simple shapes instead of digits); however, one of the randomly assigned shapes was superimposed. Following the prime display, subjects experienced a probe display that required them to respond either to the previously primed distractor (one of the flanking digits), the primed target, or a new target (one that was not previously primed). Negative priming was considered present when the subject's performance was poorer on the primed distractor than on the control display (the novel target). On the other hand, positive priming was considered present by superior performance on the primed target than the control display. The results of the study confirmed the effectiveness of the stress and load manipulations. Moreover, it was found that as stress increased, the negative priming effect diminished. This was the case only when the load was considered low. When load was high, the negative priming effect was present as expected. The author concluded that stress does not improve selective attention. On the contrary, Braunstein-Bercovitz contended, "…stress impairs selective attention by enhancing the amount of attention allocated to the distractors." (p. 354). Thus, attentional resources were depleted under the high-load conditions in stressed individuals, resources that might otherwise be allocated to the distractors. This conclusion falls in contradiction with much of the previous literature reviewed on the effects of stress on attention. However, the author's study demonstrates that there is an interaction effect between workload and psychological stress. When workload is relatively low and stress is high, the selective attention effect is present (negative priming is attenuated). On the other hand, when both workload and stress are high, support for the selective attention hypothesis diminishes and the negative priming effect is strong.

Attentional Theories and Perspectives

Chajut and Algom (2003) reviewed the three main theories of selective attention under stress and the literature support for each theory. They indicated that the first, *attention approach,* states that stress depletes an individual's attentional resources. This narrowing of attention results in greater focus on the central task which tends to enhance performance. The second, *capacity-resource theory,* also states that stress narrows attention; however, this is directional in that one attends to whatever is proximal, highly accessible, or automatic (be it relevant or irrelevant to task or goal completion). Finally, the third approach, *thought suppression,* states that attention is a conscious pursuit but that there is also an unconscious process of automatic search for "to-be-suppressed" material that occurs simultaneously (i.e., whatever you do, don't look down). The ironic aspect of this process is that this sensitizes the individual unconsciously to monitor what he or she should not. This monitoring results in a draw on attentional resources (amplified under stress) which leads to a hypersensitivity toward task-irrelevant cues (the to-be-suppressed thoughts).

There is support for each perspective in the literature. In order to establish which hypothesis was most explanatory, Chajut and Algom (2003) used the Stroop and reverse Stroop effect within the Garner speeded classification paradigm (a four block trial of various Stroop tasks). Their experiments were conducted under two conditions, low and high stress-task difficulty, using the stress of time pressure and threat to ego as their manipulations. While the Stroop task is the most widely used instrument in the study of selective attention, this paradigm has been challenged by some (MacLeod, 1991). In their review of the Stroop literature, Chajut and Algom cite mixed results—stress facilitates, degrades, and has no impact on performance. However, in their own investigation, these authors found that stress reduced interference and improved selective attention (low stress allowed for irrelevant information intrusion and significant Stroop effects). These findings argue for the attention approach and are inconsistent with the other two. The authors note that previous studies examining divided attention might well find decrements in performance due to the narrowing of attentional processes (the very same phenomenon that makes selective attention better). These authors attempted to replicate their findings under the stress of noise and achieved similar results. Once again the authors tested the theory by replacing stress with motivation (i.e., financial incentive) and increased class credit (to ensure that stress was the operant variable). This design found that the motivation used did not elicit improvements in selective attention. As a result, the authors concluded that motivation and stress may have different effects on cognitive processes.

Mack (2003) posits that we frequently encode information beyond our present awareness (implicitly) and that this information may or may not have been attended to. For example, objects are present in our visual fields that we see without processing them into our consciousness. Mack suggested, "…observers generally do not see what they are looking directly at when they are attending to something else." (p. 181). There is some debate as to whether this reflects inattentional blindness or amnesia, but there is greater support for the visual inattention than the forgetting hypothesis. As Mack points out, unseen items are capable of priming (which can only occur if there is some memory of the stimulus even if it is an inaccessible memory). He argues that implicit perception occurs outside of awareness and cites empirical evidence that suggests that perceptual processes for grouping stimuli in the perceptual field appear to operate outside of attention. This data seems to indicate that attention is captured only after the meaning of a stimulus has been processed. It should be noted that this perspective is not widely accepted and there is data supporting the opposite position. Mack believes that what unattended stimuli are processed is related to perceptual load. When overloaded cognitively, cues are more likely to fall into inattention than otherwise would be the case.

Table 5 lists research studies on the effects of stress and workload conditions on sustained attention and vigilance task performance.

Table 5. Studies showing negative effects of stress on attention.

Source	Stress Manipulation	Task	Setting
Baranski, Gill, McLellan, Moroz, Buguet, & Radomski (2002)	Sleep deprivation	Vigilance, serial response times, logical reasoning, visual comparison, math, & multitasking degraded	Laboratory
Blake (1967)	Circadian rhythm desyncrony	Vigilance decrements	Laboratory
Braunstein-Bercovitz (2003)	Threats to self-esteem	Discrimination	Laboratory
Colquhoun (1971)	Circadian rhythm desyncrony	Vigilance decrements	Simulation
Keinan (1987)	Threats of shock	Decision scanning decrements	Laboratory
Keinan, Friedland, Kahneman, & Roth (1999)	Threats to self-esteem	Attentional control decrements	Laboratory
Kjellberg (1990)	Noise	Vigilance, reaction times & verbal comprehension degraded	Real-World
Lieberman, Bathalon,Falco, Georgelis, Morgan, Niro, & Tharion (2002)	Military combat simulation	Learning, working memory, & logical reasoning degraded	Simulation
Pepler (1958)	Heat	Vigilance decrements	Laboratory
Samel, Wegmann, Vejvoda, Drescher, Gundel, Manzey, & Wensel (1997)	Sleep deprivation	Vigilance decrements	Real-World
Schmidgall (2001)	Noise	Perceptual-psychomotor & vigilance/scanning tasks degraded	
Stokes, Belger, Banich,	Alcohol, depression, &	Visual-spatial	Laboratory

& Bernadine (1994)	stress	processing degraded	
Stokes, Kemper, & Marsh (1992)	Time pressure	Attention & vigilance degraded	Simulation
Temple, Warm, Dember, Jones, LaGrange, & Matthews (2000)	Sustained attention (the task itself)	Vigilance decrements	Laboratory
Van Galen & van Huygevoort (2000)	Time pressure & workload	Vigilance & visual tracking degraded	Laboratory
Vasmatzidis, Schlegel, & Hancock (2002)	Heat	Vigilance, visual tracking, & auditory discrimination degraded	Laboratory
Wickens (1992)	Stress	Signal detection & vigilance task degraded	
Wickens, Stokes, Barnett, & Hyman (1991)	Time pressure, noise, & financial risk	Attention & vigilance degraded	Simulation
Wilkinson (1964)	Sleep deprivation	Vigilance decrements	Real-World
Williams, Lubin, & Goodnow (1959)	Sleep deprivation	Vigilance decrements	Laboratory

Summary of Findings and Limitations to the Literature

The research literature concerning stress' effects on attentional processes is relatively clear. Psychological stress along with various forms of workload tend to tunnel attention, reducing focus on peripheral information and tasks and centralizing focus on main tasks. What distinguishes a main task from a peripheral task appears to depend on whichever stimulus is perceived to be of greatest importance to the individual or that which is perceived as most salient. Threat-relevance is strongly associated with salience. Therefore, when environmental stimuli are threat-related, such stimuli are often considered to be most salient by the individual. This tunneling of attention can result in either enhanced performance or reduced performance, depending on the nature of the task and the situation. For instance, when peripheral cues are irrelevant to task completion the ability to tune them out is likely to improve performance. On the other hand, when these peripheral cues are related to the task and their incorporation would otherwise facilitate success on the task, performance suffers when they are unattended. This finding may apply to both visual attention and auditory attention; however, auditory attention has received little study. Experimental designs that incorporate a stress manipulation check (assessing the effectiveness of the supposed stress manipulation) are unfortunately not common. Researchers often only assume that their manipulations (e.g., increased workload, time pressure, physical or emotional threat, etc.) function as psychological stressors. Further, most of these studies fail to distinguish possible direct effects of manipulations from indirect effects.

Later in this report I will present a model that includes postulated mechanisms by which stressors might affect attentive processing (refer to appendix C).

The Effect of Stress on Memory

The research literature concerning the effects of stress on memory consistently demonstrates that elements of working memory are impaired. Although the mechanisms behind these effects are poorly understood, it seems likely that encoding and maintanence processes are the most affected. Some have concluded that this reflects a reduction in resource capacity. Resources may be eliminated in some way, the span of time in which they can be accessed may be reduced, or these resources may be drawn away as a result of resource sharing (the absorption of resources by competing demands). Furthermore, little is known about what stage in the process this depletion or occupation takes place. It may be that resources or capacity are reduced at several points in the process (i.e., encoding, rehearsal, or retrieval). Few, if any, studies have attempted to separate these dimensions within memory processes while under stress conditions.

Working Memory Overview

Prior to a detailed discussion of the putative effects of various stressors on memory function and performance, a brief discussion of memory (particularly working memory) is appropriate. Memory has long been conceived of as a multicomponent system which includes a long-term memory store and a short-term or working memory component. Baddeley (1986) proposed a model of working memory that suggests individuals have a limited pool of working memory resources that are available to compete for various tasks. Thus, divided attention or dual-tasks draw from this pool, resulting in a reduction of resources to devote to any one task. Baddeley has posited a tripartite model of supervisory control over memory consisting of a central executive and two slave systems, an articulatory loop and a visuospatial sketch pad (specializing in language and spatial material respectively). While the central executive function is somewhat ill defined at this time, Baddeley has characterized it as, "…an attentional control system…." (p. 486). The essential purpose of working memory appears to be the maintenance of a small subset of long-term memory in a readily accessible state.

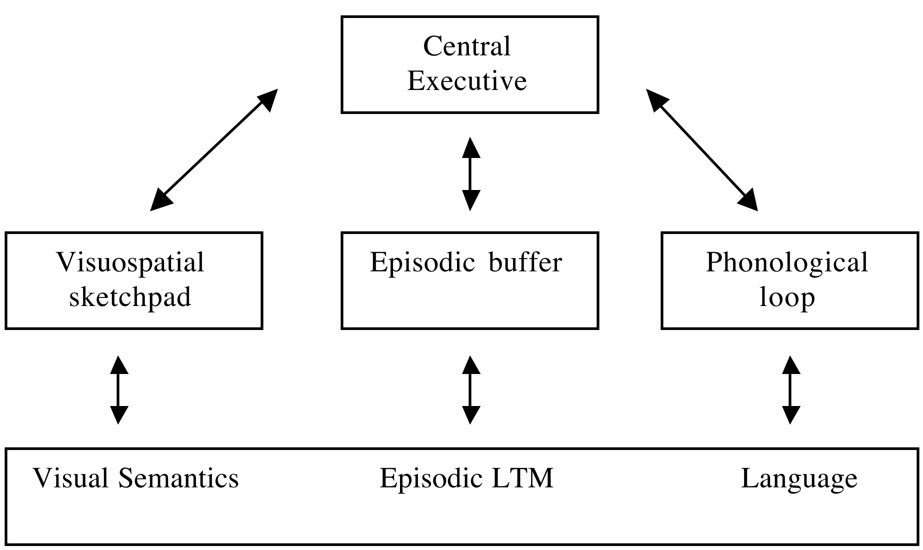

Figure 4: the figure above represents Baddeley's current model of working memory (Baddeley, 2002).

Memory, Stress Effects, and Anxiety

There are a variety of tasks in which memory has been measured under stress. To be more precise, these investigations have typically addressed working memory, and unless otherwise specified in the text, the reader should consider general references to memory as references to working memory (much of the research contained in this review fails to make this distinction explicit). Typically, long-term memory remains intact under stress; however, various elements of working memory are more vulnerable.

Anxiety is perhaps the most common stress condition by which memory researchers have examined memory performance (Eysenck, 1979; Eysenck, 1985; Wachtel, 1968). Anxiety has been generated in a number of ways but most frequently by way of math performance. The negative effects of this stressor on working memory are well established (Ashcraft, 2002; Ashcraft & Kirk, 2001; Eysenck, 1992; Eysenck, 1997). Ashcraft and Kirk (2001) reported that individuals high in anxiety tend to be slower and more deliberate in their processing of various aspects of mathematical functions. For example, these individuals seem to have particular difficulty with the carry-over function (i.e., adding a column of numbers that sum greater than nine). Given the relationship between this function and working memory, researchers have conjectured that the additional anxiety present in highly anxious subjects likely draws away resources that could otherwise be used in working memory for activation and rehearsal (such as that needed for the carry operation). Although it has been contended that high-math-anxious individuals may simply be less adept at math (deficits owed to ability and not anxiety per se), various investigations have provided evidence that math competence is not adequate to explain the phenomena (Hembree, 1990). Instead, research has directed our understanding toward resource depletion models. Specifically, it has been asserted that worry and intrusive cognitions compete for the limited pool of resources. This competition results in fewer resources available to the primary task, in this case mathematical calculation. Eysenck and Calvo (1992) have referred to this position as processing efficiency theory and have proposed that highly anxious individuals tend to demonstrate lower cognitive efficiency accordingly.

Ashcraft and Kirk (2001) examined the the effect of math-related anxiety on the performance of various cognitive tasks, predicting that math anxiety would disrupt working memory, leading to a degradation in mathematical and related performance. Specifically, these authors measured the degree to which subjects were math-anxious (using a self report index - short Mathematics Anxiety Rating Scale) followed by a performance assessment on two measures of working memory (listening span and computational span). Their results suggest that individuals scoring high on measures of math anxiety tend to perform worse on measures of working memory. While this was true across both measures (not necessarily limited to just computational tasks), highly anxious subjects were more likely to demonstrate deficits in computational scores than listening scores. These findings led the researchers to conclude that working memory capacity was degraded by math anxiety. In a second experiment, they examined their hypothesis using an on-line task of mental addition varying in levels of difficulty under timed conditions. Furthermore, these were paired with an additional task. The reason for examining dual-tasks was based on the assumption of resource competition. The authors suggested that error rates or decrements in response times should reflect capacity of working memory. Accordingly, they embedded their original addition task with a memory task requiring them to maintain two or six randomized letters in memory. Those subjects reporting the highest degrees of math-related anxiety scored worse than those reporting low to moderate levels of anxiety. Particular difficulty for math anxious subjects was observed in performing carry operations (using the tens column in addition tasks). These deficits were not found with nonnumerical stimuli.

To extend these findings, the authors implemented a third experimental paradigm. It has been suggested that anxiety's influence on math performance may differ depending on the degree of working memory required for the task. Some calculations are very working memory intensive while others rely heavily on math information well-learned previously. Moreover, these authors explored whether or not the anxiety incurred is related to mathematical operations specifically or more generally to numeric processing. Ashcraft and Kirk (2001) assessed a third group of subjects (similar to their first two experiments) using the same self-report measure of anxiety and the listening-span and computation-span tasks; however, they added a transformation task requiring subjects to transform letters and numbers in a series of trials. Under the letter transformation task, these individuals were presented either two or four letters (one at a time) and were asked to transform the letter mentally by proceeding forward in the alphabet either two or four positions. These new letters were then held in working memory pending a recall phase all the while transforming the next letter. Similarly, under the numeric task, a number was presented and subjects were asked to transform it by a value of either seven or thirteen. Once transformed these numbers were then held in memory while additional operations were conducted. The authors' results demonstrated that math anxiety significantly degraded performance in terms of accuracy and response time on tasks that were heavily dependent on working memory. In addition, they showed that arithmetic calculations are not needed to replicate the deficits found in math-anxiety research. Such findings can be created by simply using a numerical counting task. Ashcraft and Kirk also found that highly anxious subjects spent more time on task than subjects with low anxiety yet did not raise the accuracy of their results to the level of those with low anxiety. This suggests that although these individuals may have invested more effort in the task, this investment did not yield an improved result.

Ashcraft (2002) provided a 30 year review of the math-anxiety research and in doing so came to several conclusions. Investigations have consistently found that simple single-digit calculations (i.e., 2 + 7 = 9) do not appear to be plagued by anxiety effects. They are unlikely to be effected by anxiety because they do not require a substantial investment of working memory resources. However, only slightly more complex calculations (i.e., 15 + 43 = 58) show rather significant decrements as a result of math anxiety. Furthermore, traditional arithmetic is not required to elicit these responses. On the contrary, number counting and other tasks that are "math-like" appear to be sufficient to create math-anxiety states and result in performance degradation. This degradation takes the form of an increase in processing time (on average about three times the amount required for individuals with low anxiety) and accuracy (twice the number of errors found in subjects with high math anxiety). Mathematical and numeric tasks that rely heavily on working memory capacity are more sensitive to the effects of anxiety than those that do not.

What Mechanisms Explain the Anxiety-Memory Deficit?

There is some consensus that anxiety occupies resources or "space" in a limited capacity system, thus diverting resources from tasks requiring memory capacity. Ashcraft (2002) found results consistent with Eysenck and Calvo's (1992) model that proposed that anxiety (i.e., math anxiety) disrupts working memory as individuals devote attentional resources to their intrusive thoughts and worries rather than to the task at hand. With fewer resources devoted to encoding and rehearsal, fewer memories are likely to be available for recall, and the quality of those memories may suffer as well. Diminishing resources may impede the rehearsal process used to maintain elements in working memory, causing intermediate steps of math problem-solving to be dropped, requiring those steps to be repeated or reconstructed for successful performance (this in turn delays performance and would require further resources). Tohill and Holyoak (2000) found that anxiety (associated with speeded arithmetic) reduces the scope of working memory, affecting abstract analogies more than concrete analogies. Dutke and Stober (2001) also asserted that worry occupies more space in working memory in highly anxious individuals, which limits available resources for tasks. They found that making task demands sequential rather than concurrent had beneficial effects on performance. The authors believe that these represent external processing aids, helping to compensate for restricted memory functions—a perspective that is shared by others as well (Matthews, 1996). Kellog, Hopko, and Ashcraft (1999) explored the processing efficiency theory put forth by Eysenck and his colleagues (Eysenck, 1992; Eysenck & Calvo, 1992). Their investigation replicated previous findings that show the differential impact of anxiety on math performance between individuals with high anxiety and those with low anxiety. Moreover, the authors argue that these differences become more pronounced as the difficulty of the arithmetic tasks increase. Kellog et al. explored the relationship between time pressure and performance under similar conditions, predicting differential effects between groups (i.e., individuals high in math-anxiety would perform proportionally worse). However, their results indicated that the stress of time pressure lowered performance in both anxious and non-anxious individuals on arithmetic tasks equally. The authors concluded that this finding fails to support the anxiety resource model and further suggests, "…that time pressure does not appear to be a critical component of the anxiety/performance deficits relation." (p. 598).

The effects of divided attention on memory performance may be related to the discussion above. While this subject will be addressed in further detail in a later section, I illustrate the issues briefly here as well. Analogous to the role of anxiety described previously, secondary tasks require and draw away resources and attention from the primary task. Thus, dividing attention between tasks reduces the attentional resources available to apply to either task. In such cases when the recall or recognition of information is required, this division often results in a decreased capacity to recall or recognize information from memory. It has been demonstrated that dividing attentional resources has a direct negative effect on the encoding of information into memory (Baddeley, Lewis, Elderidge, & Thomson, 1984). Naveh-Benjamin, Guez, and Marom (2003) suggested that several mechanisms may be at work. For example, according to Craik, Govoni, Naveh-Benjamin, and Anderson (1996), a division in attention may lead to a reduction in the time available to process incoming stimuli (due to time devoted to a secondary task). Similarly, incoming information may be subject to less depth and less elaborative coding when attentional resources are divided.

Naveh-Benjamin et al. (2003) have explored a third hypothesis, referred to as the associative deficit hypothesis. From this perspective divided attention disrupts the, "…mechanism responsible for associating different components of an episode into a coherent unit." (p. 1022). The authors state that as a result a fragmented unit of information is encoded into memory. To test this hypothesis the authors devised five experiments using a concurrent visual or auditory continuous choice reaction time task. During their initial experiment subjects were exposed to unrelated items (word-nonword pairs) while engaged in the concurrent task. In subsequent trials, different sets of subjects were exposed to variations of this initial paradigm: unrelated word-word pairs, and perceptual-contextual pairs (form-font pairing). Across all of the conditions of the first three experiments the investigators found no difference in memory performance between the recognition of associative information and item information. The associative deficit hypothesis was not supported. In their fourth and fifth experiments, Naveh-Benjamin et al. exposed subjects to six lists of unrelated word pairs under measurements of free recall, cued recall, and recognition. Neither of these additional designs resulted in findings that supported the associate deficit hypothesis. The authors concluded that the underlying mechanism that causes diminished memory performance as a result of divided attention is not likely to be attributable to a disruption in the processing of relational associations between episodic information units. Instead, Naveh-Benjamin and colleagues suggested that divided attention effects information processing at some other stage of the encoding process. For example, they suggested that disruption may occur during the initial perception of the stimulus, at the point of component encoding, binding, or perhaps during the elaboration or consolidation of the memory units.

Memory and Other Putative Stressors

There is evidence that other sources of stress (noise, threat, thermal conditions, etc.) reduce working memory performance. For example, several investigations have found that noise increases the incidence of errors on working memory tasks (Finkelman, Zeitlin, Romoff, Friend, & Brown, 1979; Gomes, Martinho-Pimenta, & Castelo-Brano, 1999; von Wright & Vauras, 1980). Hockey (1979) provided a review of the research on the effects of noise on performance and information processing. He concluded that noise has several effects: 1) it tends to over-arouse an individual, which results in a speed/accuracy trade-off in performance, 2) it changes attention allocation which reduces working memory, 3) it creates attentional selectivity or tunneling, 4) it increases response selectivity, and 5) it tends to reduce a person's confidence in his/her performance. Thus, Hockey viewed the negative effects of noise on memory as eminating from earlier effects on attention. Evans, Hygge, and Bullinger (1995; 2000) argued that such effects may be reversible. Wickens, Stokes, Barnett, and Hyman (1991) studied the effect of various “stressors” (time pressure, noise, and financial risk) on working memory. They found that these factors tended to worsen memory performance but not for declarative knowledge tasks. This finding may reflect the resilence of long-term memory despite the presence of stressful conditions.

Previous investigations into memory performance have found negative effects across a variety of putative stressors including: fatigue (Davies & Parasuraman, 1982; Eysenck, 1985; Gevins & Smith, 1999; Kleitman, 1963), alcohol intoxication (Gevins & Smith, 1999), simulated military combat (Lieberman, Bathalon, Falco, Georgelis, Morgan, Niro, & Tharion, 2002), and the thermal stresses of both heat (Hocking, Silberstein, Lau, Stough, & Roberts, 2001) and cold (Giesbrecht, Arnett, Vela, & Bristow, 1993). For example, Giesbrecht, Arnett, Vela, and Bristow (1993) found that after immersion in cold water, tasks requiring minimal cognitive demands remained unaffected (auditory attention, Benton visual recognition, digit span forward); however, those tasks deemed more cognitively challenging, requiring work memory (digit span and the Stroop task), showed significantly degraded performance. Slaven and Windle (1999) devised a unique experimental paradigm—simulating a disabled submarine. These researchers found that under the stress of cold, there were no significant performance decrements on measures of working memory. However, self-report measures suggested that decrements were subjectively perceived. These authors conjectured that motivation, spurred by the presence of peers, may have played a role in mitigating the effects of the cold. This conclusion is consistent with the notion that “misery loves company” whereby sharing a negative experience with others relieves some of the negative effects on the individual. This moderating variable is discussed further in a later section of the review.

Burrows (2002) examined memory performance under conditions of workload (an increasing list of words) and time pressure (the speeded presentation of information) measuring the accuracy and speed of recall on a recognition test. Burrows’ initial experiment was designed by presenting a list of six words, each word being held visible for two seconds following which it was replaced (on a computer screen) with the next word. The list of words was presented twice to each subject. During the subsequent recognition test, subjects were asked to determine as quickly as possible whether the word appearing was on the previous list or not. Burrows conducted 12 trials, half consisting of target words previously presented and half consisting of new words. After completing these trials each subject was asked to rate their subjective stress level and their perceived level of performance (how well they felt they had done). Burrows then presented a second list of six words instructing the subjects to add these additional words to the original list. Following a similar 12 trials and subsequent self-ratings, these subjects were then presented an additional list of six words. This process continued until each subject had been exposed to 60 words and 120 recognition trials. Self-rating of stress and perceived success at the task were also assessed throughout these iterations. Three days later, each subject was then re-tested (a similar series of memory trials was used). Results from this experiment indicated that memory accuracy gradually decreased as workload (the number of items to be remembered) increased. For example, after exposure to just six words subjects averaged 95% correct upon recognition. This proportion dropped gradually to just over three-fourths after all 60 words had been presented. Similarly, the increase in words to be remembered resulted in a strong correlation with self-rated stress ($r = .98$), thus stress ratings mapped exceptionally well to measures of workload and decrements in memory performance. The author noted that while the drop in memory accuracy was significant and substantial, this decrement was gradual across the accumulation of memory items. This pattern was also demonstrated across measures of response time. Subjective rating of performance accurately represented objective measures, suggesting that subjects were aware of and accurately perceiving their own decremented performance.

Burrows also manipulated the length of the word lists from six to 15, 30, 45, and 60 depending on the group. The remaining conditions were kept static. The data resulting from the 120 trial sequence was very similar to the previous set of findings. Memory accuracy dropped gradually to just over 80% after the full 60 words were presented. A similar decline was reported in reaction time (averaging approximately 3ms per word added). During a third experiment, Burrows manipulated the length of the word lists from six to 12, increasing the amount of material to be remembered. Once again, the results of this experiment mimicked the other two, finding a significant, but gradual decline in memory accuracy as the total length of words to be remembered (recognized) increased. The proportion of words recognized after just 12 trials was nearly 95%; however, by the time 60 words had been presented for memory the proportion recognized had dropped to below 80%. This number further declined but shallowed out as the number of items exceeded 100. Reaction times also declined to a point as did self-ratings of stress and performance. Burrows concluded from these three experiments that the increase in workload concomitantly resulted in an increase in subjective stress level and resulted objectively in gradual, not sudden, decrements in recognition memory accuracy and reaction time.

In an attempt to examine the effect of speeded presentation on recognition (elements of workload and time pressure), Burrows conducted two further experiments. The first assigned two groups of participants to one of two conditions. The first received identical treatment to those in experiments 1–3 described above (presentation times of two seconds per word). The second group also received similar conditions as described above, but with only a .5 second presentation of each word. The results suggested that self-rated stress increased as workload increased for both groups. Recognition accuracy was worse for the speeded group (approximately 10% worse). The proportional difference between the two groups remained equivalent as performance declined throughout the task. Based on self-rated performance it was clear that those in the speeded group were aware that their performance was appreciably degraded. Burrows concluded that the loss in time corresponded to a loss in the ability to encode and that the differential loss in recognition memory was attributable to limitations in encoding. In his fifth and final experiment, the author explored the impact of introducing a function of information updating into the list-memorization procedure. Specifically, he asked subjects to delete and replace previously viewed words with newly presented words, later requiring them to determine which items had replaced the words and which had been deleted from the lists. Once again two groups of subjects were observed, one receiving the same conditions previously experienced while the other performed under the memory reorganization condition. The results of this experiment demonstrated a similar pattern of performance decrement to that previously described for all but the reorganized memory items. Performance on these items dropped dramatically, nearing chance. Burrows concluded, "…moving items from a state of never having been shown to a state of having been shown, and then to a state of being deleted leads to performance that literally reflects lack of memory ability." (p. 30). Overall, Burrows reported finding a gradual decline in recognition memory as both stress and workload increase. Furthermore, reducing the time for encoding of words appeared to reduce the accuracy of later recognition of those words. Stress and workload also relate to concomitant increases in reaction time. Finally, when the reorganization of memory items is required, the ability to accurately recognize words that have been removed from memory categories versus those that have been added to them is dramatically affected.

Burrow's set of experiments provide support for three main assertions: 1) increasing the volume of to-be-remembered material decreases the recognition of that material gradually and not dramatically, 2) reducing the time available for memorization of new material also results in a decrease in performance; however, not one that is catastrophic in nature, and 3) when to-be-remembered items are reorganized in memory (see final experiment for description of procedure) there is a dramatic effect that resembles the total loss of memory.

Stress, Cortisol, and Memory

Cortisol, having previously been established as a physiological measure of stress, has also been examined in relation to memory functioning. Al'Absi, Hugdahl, and Lovallo (2002) measured cortisol levels in subjects after they completed mental-arithmetic and public-speaking tasks. Their results indicated that high-cortisol responders performed worse than low-cortisol responders on mental arithmetic, but better on dichotic listening. The authors suggested that the performance enhancement on dichotic listening may have resulted from a focus of attention (Easterbrook's narrowing-attention hypothesis). Al'Absi and colleagues reported that high cortisol responders rated their moods more negatively than low responders. This finding further links the relationship between perceived stress, cortisol activation, and performance. These investigators concluded that cortisol disrupts working memory but enhances selective attention. Newcomer, Selke, Nelson, Hershey, Craft, Richards, and Alderson (1999) examined the role of cortisol (simulating stress) in degrading memory function as well. They subjected individuals to cortisol levels consistent with the psychological stress response experienced pending surgical procedures. They found that exposure to cortisol levels induced by such stress results in a temporary decrease in verbal declarative memory. These authors measured verbal memory through an immediate and delayed paragraph recall task (Wechsler Memory Scale-Revised Logical Memory Test). Both immediate and delayed recall was affected by the increase in cortisol. This decrement in performance was removed following a return to normality in cortisol blood levels. Performance was not found to be degraded significantly when assessing nonverbal memory, sustained or selective attention, and executive function tasks (continuous performance task, spatial delay response task, and the Stroop color-word task). The authors did not speculate as to the underlying mechanism affected by the cortisol (e.g., encoding processes, rehearsal, retrieval, etc.).

Vedhara, Hyde, Gilchrist, Tytherleigh, and Plummer (2000) noted that student exam periods appeared to be related to an increase in self-reported stress (as one might expect); however, this corresponded unexpectedly to a decrease in cortisol levels. This profile was associated with an increase in short-term memory performance (hippocampal-specific short-term memory) without negative effects on auditory verbal working memory. Moreover, the increase in subjective levels of stress and decreased levels of salivary cortisol corresponded to degraded performance on measures of selective attention (telephone search task) and divided attention (telephone search and counting task). The authors concluded that cortisol is related to cognitive performance but that its effects are selective. Vedhara and colleagues note that there may be a curvilinear relationship between glucocorticoids and cognitive functioning. In this way, the selectivity of effects incurred by increased cortisol exposure may be a result of differences in cognitive appraisal as well as differences in the peak of the inverted U. In a related study, Diamond, Fleshner, Ingersoll, and Rose (1996) examined the relationship between stress, hippocampal impairment, and memory. The authors formulated a strong case for the connection between hippocampal function and memory. Furthermore, they empirically linked the hippocampus to regulatory functions over corticosterone recepters and ultimately behavioral responses to stress. Diamond and colleagues indicated that extended exposure to stress (and concomitantly to hypersecretion of cortisol), results in damage to the hippocampus (neural loss) and impairment in learning. In addition, these authors reported that this exposure has also been found to block hippocampal potentiation—often considered a central-feature in the modeling of memory from an electrophysiological perspective. In their investigation, Diamond et al. studied the effects of stress on hippocampal functioning in rats measured by performance on a maze task. The results of this investigation showed that after being placed in a stressful environment, rats' working memory and their subsequent ability to learn was impaired. This effect was not found in measures of reference or long-term spatial memory. The authors concluded the hippocampal-specific learning (i.e., declarative memories) may be particularly sensitive to the effects of stress on working memory functioning.

Emotional Memories, Trauma, and Tunneling

There is a compelling literature that has questioned the ability of individuals to accurately reflect on and report their own mental processes (Nisbett & Wilson, 1977). Furthermore, this lively debate has been extended to memory recall in naturalistic settings (Christianson, 1984; Loftus, 1980). Numerous studies have shown quite conclusively that merely imagining events can induce a false memory for the event (Heaps & Nash, 2001; Hyman & Pentland, 1996). Moreover, the more an event is imagined the more likely an individual is to believe that it really occurred (Goff & Roediger, 1998; Lampinen, Odegard, & Bullington, 2003). As one might imagine, the addition of emotion in memories reduces our confidence in those memories further. The emotionality of events appears to be related to the quality and content of what is remembered. Kramer, Buckhout, Widman, and Tusche (1991) exposed subjects to emotion-arousing traumatic stimuli (images of murder victims). Their results demonstrated that subjects' memory was poorer for stimuli following exposure to emotional content. The emotion-arousing image was highly salient and well-remembered; however, exposure to this resulted in interference with the encoding of a subsequent image. Payne, Nadel, Allen, Thomas, and Jacobs (2002) found that under stress individuals were more likely to experience false memories (the false recognition of semantically related words that were never presented for study). The majority of studies examining the effects of emotion on memory have not attempted to tease apart whether these effects center on encoding, rehearsal, or retrieval processes.

Christianson (1992) provided an extensive literature review of eyewitness memory under conditions of arousal, stress, and acute negative emotional states. He posited that Easterbrook's notion of a restricted range (centralized attentional cue sampling) could be used to characterize memory under stress. His review of the research on stress and memory points toward several conclusions: 1) memory tends to be impaired temporarily when recalling events prior to or following an emotional event, 2) memory for the emotional event is not necessarily skewed or impaired under stressful conditions, 3) there is a tendency for improved recall for central-features when such events are emotional as compared to neutral, 4) improved recall for such events does not consistently hold up under conditions of cued or recognition recall, 5) peripheral details are less often remembered when the main events witnessed are emotional in nature, 6) the difference in recall may relate to attentional selectivity as visual scan studies suggest that individuals, "fixate faster, more often, and for longer durations” on emotional items (p. 292); however, Christianson’s own experiments argue against this conclusion, 7) memory tends to be affected by context effects; specifically, it improves when retrieval conditions are congruent with encoding conditions (i.e., mood-congruency effects), 8) research points to the notion that individuals may be predisposed or emotionally primed toward emotionally valent information, and finally, 9) there appears to be very little difference between laboratory and real-world findings concerning emotional arousal and memory performance. As stated, Christianson proposed that emotional events are remembered differently than neutral events. He further pointed out that it is not the case that the stronger the emotion the worse the recall. He believes that this model is far too simplistic. On the contrary, he asserts that highly emotional events are typically retained, particularly their central characteristics (but not to the exclusion of all peripheral detail).

Memories also tend to show a preference toward mood-congruency. Russo, Fox, Bellinger, and Nguyen-Van-Tam (2001) examined the memory recall of individuals identified as highly anxious. They found that these individuals were more likely to recall mood-congruent stimuli than those identified as low anxious. Thus, the affective state of an individual may function in any number of ways toward mood congruency: 1) it may prime individuals for mood-congruent information in memory, 2) it may limit informational processing toward attentionally biased stimuli, or 3) it may sensitize the activation, rehearsal, or availability of mood-congruent material. These assertions highlight the important role of state-dependency in learning under stressful conditions. That is to say, individuals tend to remember more and perform better in general when under similar conditions to their original learning environment. This appears to be even more pronounced when the emotional valence of the information is congruent with the individual’s emotional state (i.e., remembering sad things when one feels sad). Lang, Craske, Brown, and Ghaneian (2001) demonstrated the effects of state-dependent learning under fearful and relaxed settings using a word recall task.

Related to these findings is the notion that memory, under stressful conditions, tends to channel much in the same way as attention does. There appears to be at least some evidence for this tunnel memory hypothesis (Christianson & Loftus, 1991; Christianson, Loftus, Hoffman, & Loftus, 1991). Berntsen (2002) explored the memory constriction hypothesis that suggests that stress effectively “shrinks” memory resulting in a predominance of central-feature memories (in this case autobiographical in nature). In Berntsen’s first experiment he attempted to replicate findings from Christianson and Loftus (1990) and Wessel and Merchelbach (1994), who found a preponderance of central-feature memories when subjects were asked to recall memories of emotional or traumatic events. In his design, participants were asked to recall their most shocking experience along with as many details about this event within a specified time period. Furthermore, subjects were asked to write a description of the event including these details. After this portion of the experiment participants completed a brief questionnaire concerning their memory of the event. The classification of memory details as central or peripheral was carried out by two independent judges. Berntsen’s results revealed a strong preference for central-feature details (three times the proportion). It was also observed that the more emotionally intense, the greater the tendency for central-feature detailed memories.

During a second experiment, Berntsen divided subjects into two groups; one experienced the same conditions as those described above while the other was asked to recall and describe their happiest memory. Both groups recalled the same number of detail memories, but there was a significant difference in the quality of the memories recalled between groups. The results of this study demonstrate that memory for central-feature details tend to occur under negatively valent memories and not nearly as often for positively valent memories. Moreover, negative emotional events were rated by subjects as more surprising. This finding may relate to the effect of uncontrollability and unpredictability in augmenting the effects of stress which would in turn result in a greater negative effect on performance. In order to examine whether or not the act of recalling and recording emotionally valent memories was related to the quality of details recalled, Berntsen conducted a third experiment in which he asked participants to rate their mood prior to and following the recall and description of their event details. Berntsen was particularly interested in investigating whether or not subjects' moods changed as a result of their recall and if this change resulted in any bias in mood-congruent memory recollection. Once again both groups (positively and negatively valenced memories) recalled similar amounts of details concerning their central events. However, significantly more central-feature details were remembered by those recalling a negative experience. Mood ratings were subject to change only after participants recalled their most shocking memories and not their happiest. There was a mood-congruence effect found for word-cued memories after subjects recalled these negative events (this effect was not found for positively valent memories). Berntsen concluded that this research supports the notion of a tunnel memory hypothesis, and he proposed that emotion and gist-related portions of events appear to be more accessible to recollection when remembering stressful events. The author did not address whether this tunneling was the result of prior attentional restriction or a memory-specific mechanism.

Libkuman, Stabler, and Otani (2004) examined the relationship between arousal, emotional valence, and memory recall. Although these authors acknowledged the widespread empirical support for preattentive processing as an explanation for enhanced recall of emotionally valent material, they argued for the role of post-stimulus elaboration as a viable mechanism as well. Elaboration occurs during or following the initial encoding of the stimulus and is likely to involve the rehearsal of various event features. It has been shown to make memory for such events more resilient and less likely to be forgotten—flashbulb memories are believed to be one result of this type of elaborative process. In order to test the hypothesis that post-stimulus elaboration plays an active role in the memory of emotional events, the authors exposed subjects to both positively and negatively valent stimuli. The series of slides used for their examination were selected from the International Affective Picture System and were rated for their arousal properties (high and low) as well as their emotional valence. Subjects were broken into two groups, an elaboration group and a distraction group. Both groups were exposed to the series of pictorial slides; however, subjects in the distraction group were shown a distractor slide between each target slide that required them to perform a series of math problems (blocking the likelihood for elaboration). The elaboration group was shown a blank slide between target slides, allowing for elaboration to take place, before proceeding to the next slide. After the series of slides had been presented, both groups performed a brief filler task that was followed by a cued recall test.

The results of the study indicated that positively valent images tended to be remembered better than negatively valent images (although both types of valenced images were recalled more often and in more detail than neutral stimuli). Images that were rated as highly arousing also tended to be remembered over those rated as low-arousing. In addition, memory for central-features was better than memory for peripheral details. Support for the author's hypothesis, the role of post-stimulus elaboration, was not found. Their data suggested that only negatively valent stimuli were elaborated by subjects. This finding was irrespective of arousal-level which indicates that what enhances recall of emotional events is not necessarily arousal, but instead, may be the emotional valence (positive or negative) of the event. The authors speculated that this finding can be explained from an evolutionary perspective. For example, it may be more adaptive to initially respond based on the valence of an event when it is negative than based on arousal cues, which may reflect either a positive or negative event. Similarly, in addressing why elaboration occurred for negative images and not for positive images, the authors suggested that negative stimuli may present an evolutionary priority over positive stimuli.

Kensinger and Corkin (2003) also examined the relationship between valence and arousal in the remembrance of emotional stimuli. In contrast to Libkuman, et al. (2004), the results of their analyses suggest a greater role for arousal than valence. These authors constructed six experiments to test their hypothesis that subjects would be more likely to remember details associated with emotional words as compared to neutral words. Furthermore, they compared two types of subjective memory experience, *remembering* and *knowing*. Remembering, or recollection, has been described as a "slower attention-demanding process" that typically includes item-specific details. The second, knowing, which is based on familiarity, has been characterized as "faster and more automatic," a remembrance or feeling that one has been acquainted with the stimulus in the past (p. 1170). Distinguishing between these two types of memory experience is typically done by asking subjects whether they *remember,* or simply *know,* they have been exposed to the stimulus. Remembering the stimulus usually portends a specific and detailed memory whereas knowing suggests a sense of previous encounter without any specific detail for the item remembered. Neuroimaging research in this area has contributed to the differentiation between these two states; *remembering* is associated with left-sided prefrontal areas and the hippocampus and *knowing* is connected with the right-sided prefrontal region and the parahippocamal gyrus (Kensinger, Clarke, & Corkin, 2003).

During Kensinger and Corkin's (2003) first experiment, subjects were exposed to a series of words that were coded as either neutral or negative. Moreover, these words were also rated for their level of arousal and valence. During a self-paced recognition task, subjects were asked whether they had a vivid recollection of the word, whether they knew the word was familiar to them, or whether they thought the word was new. The results of their first experiment indicated that words rated as negative were remembered more often than those rated as neutral. This enhancement effect was predominantly true for words that subjects vividly recalled (remembered types). The authors concluded that negative words had a tendency to increase the vividness of the memories recalled, although both recollection and familiarity occurred more often for negative than neutral words. In subsequent experiments, Kensinger and Corkin (2003) assessed different measures of memory richness, varying levels of arousal and valence, and varying degrees of semantic association between words. A similar pattern emerged across all variations of study: memory details were more likely to be remembered for emotional than neutral words. Words that were rated as having a stronger valence as well as evoking greater arousal were remembered most accurately and in greater detail than neutral words. Words that were rated as arousing showed the greatest recall enhancement (over those that were rated as highly valent); however, the results of these studies demonstrate that physiological arousal is not necessary for the recall enhancement effect. On the contrary, highly valent words that were rated low in arousing quality also resulted in improved memory as compared to neutral words. The authors speculated about a number of possible explanations for these findings: 1) the distinctiveness of the stimulus, 2) the possibility of enhanced elaboration, 3) emotion's role in memory coherence—the unification of memory themes under emotional valence, 4) attention's prioritization of negative items, and 5) the effects of arousal.

Recent research has questioned the field's reliance on laboratory studies of emotional memories charging that such investigations typically expose subjects to unrealistic emotional stimuli. Laney, Heuer, and Reisberg (2003) point out that most laboratory studies examining the impact of emotion on memory employ gruesome images as to-be-remembered emotional material. In contrast to these visually-dominant displays, the authors argue that the emotion induced by natural events tends to be developmental (unfolding with the event) and rarely reflects the kind of visually shocking stimuli described above. Dubbed thematically-induced memories, the authors explored the frequency of this type of memory, as opposed to those that are typically visually-induced, in naturally occurring memories. The authors directed subjects to list personal flashbulb memories for events including the details of what occurred and their emotional state at the time. Subjects were also asked to rate how confident they were in their own recollection of the events. Following this phase of the experiment, subject's memories of their events were sent to third parties (with their consent) who could verify the event details (friends, family, etc.). These individuals were asked to rate whether subjects had accurately captured the gist of the event as well as the details associated with the event. The authors found that subject's recall of event details was surprisingly accurate (as rated by the third parties). Additionally, they found that most of the memories recalled were categorized as thematic and not visual. This categorization was based on blind coding of the recollections using a classification rubric. Visual memories were identified as those that contained a clear visual focus or central attentional object, or those that were described using a predominance of visual terms and color features. This was in contrast to thematic memories which were any that lacked these features or elements.

Given the findings that most emotional memories were coded as thematic and not visual (80%), the authors suggested that previous laboratory paradigms have employed atypical emotional memory events. Laney et al. (2003) raise interesting questions about the generalizability of such laboratory findings. They suggest that the tunnel memory and "weapon focus" phenomena, robust among laboratory studies, should be evaluated using more naturalistic to-be-remembered stimuli. Furthermore, they propose that the effect of arousal, as Easterbrook (1959) and others have posited, may be an artifactual finding. Instead, what may underlie these phenomena are the saliency of the image and not necessarily the direct effects of arousal on cue sampling.

While Berntsen (2002), Laney et al. (2003), and others have conjectured about the mechanisms that facilitate tunnel memory, our understanding of the process remains unclear. Some have argued that it results from a combination of selective attention, preattentive bias, and post-event elaboration (Christianson, 1992) while others have argued that tunneling is actually a constriction in the time to access and retrieve. For example, Miyake and Shah (1999) theorized that stress limits the time scope of memory. On the other hand, as Naveh-Benjamin et al. (2003) have suggested, there may be multiple points along the encoding process that are negatively affected by disruptions in resource allocation resulting from stress or workload. Regardless of which hypothesis is correct, it seems likely that attention plays a significant role in this modulation (if not a direct gate keeping function). For instance, attention may channel the bandwidth of perceptual cues, thus reducing the number or scope of attended stimuli. The reduction in cue sampling may in turn result in a reduction in the number of items encoded and taken into memory, thus further reducing the number or range of possible target items to be recalled or activated and rehearsed for later recollection.

Dougherty and Hunter (2003) examined the role of working memory and retrieval in the process of making probability judgments. They stated that most theories about how we make judgments assume that we compare the present decision or possibility with alternative hypotheses. Examples of these theories include: Tversky and Koehler's (1994) support theory, Windschitl and Wells (1998) comparison heuristic, and Dougherty, Gettys, and Ogden's Minerva decision making process (1999, 2001). Dougherty and Hunter have closely linked working memory and attention in the decision making process. They defined working memory as reflecting, "…individual differences in …ability for controlled attention." (p. 969). Further linking these concepts with goal structure, these authors defined sustainable controlled attention as, "…a process of both maintaining goal- or task-relevant information in the focus of attention and inhibiting goal- or task-irrelevant information from entering the focus of attention." (p. 969). The results of their experiments suggest that people do indeed make probability judgments by comparing a focal hypothesis with relevant alternatives retrieved from long-term memory. They also concluded that individuals with a large working memory span tend to include more alternatives in their comparison process, and that time constraints probably truncate the alternative generation process so that fewer alternatives are recalled from long-term memory for comparison. This notion is discussed further when examining the effects of stress on decision making.

Learning, Practice, and the role of Automaticity

Several investigations have shown that tasks that are well-learned tend to be more resistant to the effects of stress than those that are less-well-learned. Furthermore, when tasks are practiced and well-learned they are likely to be committed to long-term memory and through their frequent use (activation, rehearsal, and recollection) they tend to be more easily remembered and executed. This may result from greater accessibility. This leads them to be more resistant to the negative effects of stress; specifically, they are less likely to be forgotten and more easily recalled under stress. In addition, several authors have demonstrated that practice leads to automaticity and the proceduralization of tasks (Fisk & Schneider, 1984). When such tasks are well-learned (possibly over-learned) they tend to require less on-line control and fewer mental resources to maintain or retrieve at all (Leavitt, 1979; Smith & Chamberlin, 1992). This state tends to result in greater resistance to stress effects, which also leads to better performance than less-well-learned tasks under stress.

Beilock and Carr (2001) found support for the notion that practice leads to automaticity and proceduralization of tasks, resulting in expertise-induced amnesia (experts can't tell you what they do, they just do it). These authors examined choking related to golf putting and mental arithmetic. This finding provides support for an explicit monitoring or executive focus theory of choking (when you self focus you begin to pay attention to each step of the task which degrades performance). Examples of choking would be Tiger Woods missing a two foot putt for the PGA Open tournament or Michael Jordan missing an undefended lay up in the NBA title game. These authors highlight two theories that help explain why choking behavior in skilled performance occurs. On one hand, there is the distraction argument. It suggests that under pressure a performer's attention is drawn to task-irrelevant cues or information which diminishes the amount of on-task resources. For instance, in our golfing analogy, as Tiger sets up his putt and prepares to swing the club he might allow thoughts of worry or anxiety, "this is a big putt…I can't miss this one…can you imagine if I missed" to dominate his thought processes. Such events would absorb and divert mental resources and working memory processes away from the primary task at hand. This in turn would lead to a loss in concentration and focus and ultimately to the performance decrement.

However, the self-focus theory posits the opposite—it suggests that there is an increase in the attention paid to task-relevant dimensions. However, this theory asserts that these attentional resources are misguided. Specifically, the performer under pressure directs attention to step-by-step procedures required for a given action. This explicit focus occurs in the presence of well-developed procedural memory or implicit skills. Such a shift from implicit to explicit monitoring in procedures interferes with performance. Put another way, individuals shift from automatic to controlled processing in the execution of well-learned procedural skills. For all intents and purposes, this shift effectively transforms otherwise expert performance into novice performance. For example, the self-focus theory would suggest that a basketball player misses his free throws not because he can't tune out the crowds, but instead, because anxiety triggers within him a shift in explicit procedural monitoring that disrupts his performance. That is to say, he thinks about what he is doing too much and when this happens, he inadvertently replaces highly effective automatic execution of skilled performance with deliberate, mentally taxing processes that are poorly designed for skilled performance.

Beilock, Carr, MacMahon, and Starkes (2002) explored the effect of attention on sensorimotor skills. They found that well-learned skills do not require on-line attentional control and as a result dual-task performance is easier. When prompted to focus attention to a component of the well-learned task, performance was degraded. This led the authors to conclude that step-by-step attention to tasks is beneficial during initial learning stages but is detrimental once skills are well-learned. Katz and Epstein (1991) studied a related phenomenon, panic. However, panic performance is very different than choking. The authors argue that when individuals panic as a result of extreme stress, they do not engage in "overthink" as they do in choking performance responses but instead they stop thinking altogether and their behavior becomes primitive and maladaptive.

Allport, Antonis, and Reynolds (1972) asserted that well-learned tasks (e.g., sight-reading music) do not require constant attentional control, concluding that this results in more attentional resources available to allocate to secondary tasks. Haslam and Abraham (1987) imposed fatigue on subjects (90 hours of sleep deprivation), finding mood and mental ability declined significantly. These authors examined a number of cognitive ability measures and concluded that tasks that were well-learned suffered least. Schoenberger and Harris (1965) investigated the effects of noise level on cognitive performance. They reported that the effects observed were reduced when the task examined was well-practiced. Fisk and Schneider (1983) asserted that task consistency determines how practice affects dual-task performance. These authors paired a digit span task with either a consistent or varied mapping task. Their results demonstrated that the decrements incurred to working memory under these high workload conditions were eliminated when the task paired with the consistent mapping task was well-practiced. Practice did not improve working memory accuracy.

Consistent with the notions expressed above, Kivimaki and Lusa (1994) found that training that encourages automatic processing in operations under stressful conditions (fire fighting techniques) was most useful and least degraded under stressful conditions. Green (1985) examined three different types of stress (environmental stress, acute reactive stress, and life stress) as they relate to pilot error and aircraft accidents. The author argued that most pilots respond very well to acutely stressful situations and when surveyed report that previous experience in simulation training was the reason for their success. This self-report may imply that such training plays a role in the habituation and conditioning of possible affective responses. McKinney and Davis (2003) examined the effects of deliberate practice on pilot decision making under crisis conditions. They reported finding that deliberate practice tends to aid performance by automating it, enhancing the performer's ability to use pattern matching, and improving the accuracy of his perceptions and expectations. However, they questioned whether practice helped performance when part of this performance was unpracticed (the conditions under which most crisis situations are encountered). These authors looked at both wholly practiced scenarios (ones in which the entire crisis situation conditions had been prepared for by pilots in simulators or previous training) and part-practiced scenarios (those that included a novel component that pilots could not have prepared for).

A panel of doctoral-level pilot raters examined a series of U.S. Air Force aircraft accidents and grouped these mishaps into categories of pilot decision making effectiveness. The findings of their investigation showed that deliberate practice had a positive effect on decision making in wholly practiced scenarios. Effectiveness was also highly correlated with the number of flight hours accumulated by the pilots. There was no relationship between flight hours and the effectiveness in pilot decision making concerning the part-practiced scenarios and deliberate practice did not help decision making with these scenarios. The authors concluded that specificity of training is important. Targeting specific elements in training improves performance on those elements under crisis conditions; however, this preparation does not appear to improve pilot's readiness for novel elements under crisis conditions.

In a related study, Li, Baker, Grabowski, and Rebok (2001) found that flying experience (amount of flight time) was one of the best protective factors against a general aviation crash (after reviewing National Transportation and Safety Board reports). They suggested, as others have (Kornovich, 1992) that overtraining is a key to safety in flying. Van Overschelde and Healy (2001) also examined the role of learning as a protective factor against stress effects. They found that to help diminish the negative effect of stress on performance it helps to link new facts learned under stress with pre-existing knowledge sets. One might speculate that strengthening the association to well-learned information functions to increase the likelihood that new information will be automated and engrained.

Several authors have argued that subjects tend to "fall-back" to earlier learned responses when under stress (Allnut, 1982; Barthol & Ku, 1959; Zajonc, 1965). These previously learned strategies or knowledge sets are typically assumed to be well-learned and may be more available, easing the retrieval of such information. However, it should be noted, although it has been observed that individuals tend to revert back to entrenched learning (particularly in the facilitation of problem solving tasks), these fall-back strategies and knowledge sets may be less efficient or more error prone than less-well-learned strategies. Arnsten and Goldman-Rakic (1998) examined the stress of noise on Rhesus monkeys. Their analysis determined that exposure to acute loud noise reduced their prefrontal cortical functions, effectively taking them "off-line," resulting in a reliance on habitual responses that are mediated by posterior cortical and subcortical functions. These findings may be analogous in some circumstances to the human stress response although direct generalization of these findings is obviously difficult.

There is a building literature implicating stress in conditions for optimal learning. High degrees of stress (i.e., threat of electric shock) during knowledge acquisition phases of learning appear to degrade learning ability (Keinan & Friedland, 1984; Lee, 1961). This finding has been extended to other conditions as well. For instance, Thompson, Williams, L'Esperance, and Cornelius (2001) found that learning under the stressful conditions of skydiving altered memory and learning significantly. These authors postulated that under such stress various cues were unlikely to be encoded or associated with newly acquired information. This notion contrasts with popular wisdom that training under realistic conditions promotes performance, even when later performance occurs under stressful conditions. For example, Beilock and Carr (2001) asserted that training under realistic conditions may inoculate individuals against choking. Kivimaki and Lusa (1994) found that training that encouraged automatic processing in operations under stressful conditions was most useful. However, it should be noted that these examples illustrate the practice stage of learning and not an initial knowledge-acquisition stage.

There is some support for the idea that phased training results in the best balance between learning retention and real-world preparation. This model allows for an initial stage of knowledge acquisition to occur over minimally stressful conditions. At this point, individuals can become familiar with criterion stressors and build realistic expectations of those stressors. This stage is followed by exposure to more realistic stressors and skill practice that successively approximates the actual performance environment. Keinan, Friedland, and Sarig-Naor (1990) compared different training methods under stress (cold temperature). They reported that phased training led to the best outcome. Friedland and Keinan (1992) further evaluated such training models and concluded that graduated stress training (trainees are exposed to increasing amounts of stress over time), counter to popular opinion, tended to impair performance. This was in contrast to phased and customized training approaches that resulted in superior performance.

Summary of Findings and Limitations to the Literature

The research literature concerning the effects of stress on memory consistently demonstrates that elements of working memory are impaired. Although the mechanisms behind these effects are poorly understood, it seems likely that encoding and maintenance processes are the most affected. Some have concluded that this reflects a reduction in resource capacity. Resources may be eliminated in some way, the span of time in which they can be accessed may be reduced, or these resources may be drawn away as a result of resource sharing (the absorption of resources by competing demands). Furthermore, little is known about what stage in the process this depletion or occupation takes place. It may be that resources or capacity are reduced at several points in the process (i.e., encoding, rehearsal, or retrieval). Few, if any, studies have attempted to separate these dimensions within memory processes while under stress conditions.

There are a variety of tasks and putative stressors under which memory has been measured. Anxiety is perhaps the most common stress condition under which researchers have examined memory performance. This research has generally directed the field toward resource-depletion models. These assert that worry and intrusive thoughts compete for a limited pool of resources. This competition necessarily results in fewer available resources that can be devoted to the primary task. A complementary view contends that attention may reduce the bandwidth of perceptual cues thus reducing the number or scope of attended stimuli (following Easterbrook's hypothesis). The reduction in cue sampling may in turn result in a reduction in the number of items encoded into memory, thus further reducing the number or range of possible target items available for later recollection.

The effects of divided attention on memory performance may be significantly related to this discussion. Analogous to the role of anxiety described previously, secondary tasks require and draw away resources and attention from the primary task. Thus, dividing attention between tasks reduces the attentional resources available to apply to either task. In such cases when the recall or recognition of information is required, this division often results in a decreased capacity to recall or recognize information. It has been demonstrated that dividing attentional resources has a direct negative effect on the encoding of information, although research suggests that several mechanisms may be at work. For example, divided attention may lead to a reduction in the time available to process incoming stimuli (due to time devoted to a secondary task) or it may result in reduced depth of processing and less elaborative coding.

Several consistent observations have been made concerning memory for emotional events. First, memory tends to be impaired temporarily when recalling information prior to or following an emotional event. Second, memory for a targeted emotional event may or may not be impaired under stressful conditions; however, there is a tendency for improved recall of central features when such events are emotional as compared to neutral. These "tunnel" memories resemble what has been observed in attentional processing (Easterbrook's hypothesis). It has been argued that such memories result from a combination of selective attention, preattentive bias, and post-event elaboration. Third, peripheral details are less often remembered when the main events witnessed are emotional in nature. Fourth, memory tends to be impacted by context effects. Specifically, memory improves when retrieval conditions are congruent with encoding conditions (i.e., mood-congruency effects). Finally, research points to the notion that individuals may be predisposed or primed toward emotionally valent information.

Recent research has made the connection between hippocampal function and memory. Damage to the hippocampus often leads to impairment in learning and memory. The hippocampus is also implicated in the human stress response and the activation of glucocorticoids. Moreover, exposure to high doses of cortisol (a known marker of the human stress response) has also been found to block hippocampal potentiation. Thus, the hormonal stress response may cause direct effects on the brain structure mediating some memory functions. These neurophysiological and electrophysiological relationships appear to be the most promising link to an underlying biological mechanism and process at this time.

Tasks that are well-learned tend to be more resistant to the effects of stress than those that are less well-learned. Furthermore, when tasks are practiced and well-learned, they are likely to be committed to long-term memory, and through their frequent use (activation, rehearsal, and recollection) more easily remembered. Several authors have demonstrated that this kind of practice leads to automaticity and the proceduralization of tasks. Thus, these over-learned behaviors tend to require less attentional control and fewer mental resources, which further results in enhanced performance and greater resistance to stress. It is generally accepted that under stress, individuals tend to revert back to earlier well-learned responses. This appears to be true when these previously learned strategies or knowledge sets are over-learned and have greater availability in memory, easing their retrieval.

Finally, some research suggests that high degrees of stress during knowledge-acquisition phases of learning tend to degrade an individual's ability to learn. This finding may relate to interference or disruption in the encoding and/or maintenance phases of working memory. In an examination of learning/training models, a phased approach results in the best balance between learning retention and real-world preparation. Phased learning models typically prescribe an initial period of learning under minimally stressful conditions, followed by a graduated exposure to stress under increasingly naturalistic conditions.

Table 6 provides a sample of research studies on the effects of stress and memory performance (particularly working memory).

Table 6. Studies showing negative effects of Stress on Memory.

Source	**Stress Manipulation**	**Task**	**Setting**
Al'Absi, Hugdahl, & Lovallo (2002)	Public speaking & arithmetic	Calculations & dichotic listening	Mixed (L & R-W)
Ashcraft (2002)	Math anxiety	Calculations	Laboratory
Ashcraft & Kirk (2001)	Math anxiety	Calculations	Laboratory
Berntsen (2002)	Recall of traumatic memory& pleasant memory	Recall of event & details	Mixed (L & R-W)
Burrows (2002)	Time pressure &	Verbal recognition	Laboratory

	workload	recall	
Campbell & Austin (2002)	Time pressure	Verbal recall	Laboratory
Christianson & Loftus (1990)	Recall of traumatic memory	Recall of event & details	Mixed (L & R-W)
Davies & Parasuraman (1982)	Fatigue		WM tasks
Diamond, Fleshner, Ingersoll, & Rose (1996)	Novel learning task	Learning a maze (rats)	Laboratory
Dutke & Stober (2001)	Test anxiety	Counting task	Laboratory
Evans, Hygge, & Bullinger (1995; 2000)	Noise	LTM, WM, & reading	Airport
Eysenck (1985)	Fatigue	WM tasks	
Eysenck & Calvo (1992)	Test anxiety	Calculations	Laboratory
Finkelman, Zeitlin, Romoff, Friend, & Brown (1979)	Physical stress & noise	WM tasks (digit recall)	Laboratory
Gevins & Smith (1999)	Fatigue & alcohol	WM tasks (spatial)	Laboratory
Giesbrecht, Arnett, Vela, & Bristow (1993)	Cold	Digit span backwards	Laboratory
Gomes, Martinho-Pimenta, & Castelo-Brano (1999)	Noise (prolonged high amplitude, low frequency)	WM tasks	Real-World
Hocking, Silberstein, Lau, Stough, & Roberts (2001)	Heat	WM tasks	
Kellog, Hopko, & Ashcraft (1999)	Math anxiety	Calculations	Laboratory
Kramer, Buckhout, Widman, & Tusche (1991)	Traumatic images	Recall of details	Laboratory
Lieberman, Bathalon, Falco, Georgelis, Morgan, Niro, & Tharion (2002)	Military combat	Learning, working memory, & logical reasoning	Simulation

Naveh-Benjamin, Guez, & Marom (2003)	Divided attention	Recognition recall	Laboratory
Newcomer, Selke, Nelson, Hershy, Craft, Richards, & Alderson (1999)	Cortisol (stress simulation)	Immediate & delayed verbal recall of paragraph	Laboratory
Payne, Nadel, Allen, Thomas, & Jacobs (2002)	Stress	Recognition recall	Laboratory
Russo, Fox, Bellinger, & Nguyen-Van-Tam (2001)	Anxiety (State-Trait)	Recall	Laboratory
Slaven & Windle (1999)	Cold (disabled submarine)	WM tasks	Simulation
Tohill & Holyoak (2000)	Anxiety	Speeded calculations	Laboratory
Vedhara, Hyde, Gilchrist, Tytherleigh, & Plummer (2000)	Exam period (anxiety)	Counting task	Real-world
Von Wright & Vauras (1980)	Noise	WM tasks	Laboratory
Wessel & Merchelback (1994)	Recall of traumatic memory	Recall of event & details	Mixed (L & R-W)
Wickens, Stokes, Barnett, & Hyman (1991)	Time pressure, noise, & financial risk	WM tasks	Simulation

Note. R-W = Real-world, L = Laboratory

The Effects of Stress on Perceptual-Motor Performance

The research literature concerning the effects of stress on perceptual-motor performance consistently shows that these conditions tend to degrade performance. Most studies demonstrate this in terms of manual dexterity; however, other tasks or skills have also been shown to suffer negative effects. On the other hand, perceptual-motor skills tend to be less sensitive (more resilient) to various stress effects than higher-order cognitive processes (i.e., memory). The negative effects of stress on perceptual- and psycho-motor tasks have been demonstrated under a variety of conditions to include: noise (May & Rice, 1971; Schmidgall, 2001; Stokes, Belger, & Zhang, 1990), threat of electric shock (Ryan, 1962), thermal stressors such as heat and cold (Enander, 1989), fatigue (Buck-Gengler & Healy, 2001; Fendrich, Healy, & Bourne, 1991; Healy & Bourne, 1995; Matthews & Desmond, 2002), anxiety and fear (Baddeley, 1966; Mears & Cleary, 1980), time pressure (Van Galen & van Huygevoort, 2000), workload (Matthews & Desmond, 2002; Stokes, Belger, & Zhang, 1990; Van

Galen & van Huygevoort, 2000) and military combat (Lieberman, Bathalon, Falco, Georgelis, Morgan, Niro, & Tharion, 2002).

Baddeley led a series of experiments under real-world conditions that have been the foundation upon which subsequent research has been conducted (Baddeley, 1966; Baddeley & Fleming, 1967; Baddeley, DeFiguererdo, Hawkswell, & Williams, 1968). For example, Baddeley (1966) explored the performance differences in manual dexterity during underwater diving. This investigation employed both pressure chamber experiments as well as open-water dives. He attempted to replicate the findings of Kiessling and Maag (1962), who suggested that the negative effects of underwater pressure on the manual dexterity of divers (nitrogen narcosis), was small. Kiessling and Maag examined performance on land in a dry pressure chamber. Baddeley challenged the generalizability of the findings to real-world underwater diving, noting the differences in the environments as perceived by the divers themselves as well as the added stress of open dive conditions. He measured perceptual-motor performance using a screw plate task at different levels of depth: surface, 5-12 feet below the surface, and 100 feet below the surface. He found that time and accuracy declined under water and that performance was degraded further as the depth increased (i.e., 0–10–100 ft.). Previously, Kiessling and Maag (1962) reported very little impairment in dexterity (7.9%) but Baddeley's experiment demonstrated that these impairments were much more substantial when measured in actual underwater diving conditions (19.8%). Most of the performance decrements were observed in terms of performance speed; however, accuracy (the number of nuts left loose on the screw plate) was worse as depth increased as well. Baddeley concluded that, "…results obtained in a dry pressure chamber can not validly be generalized to performance under water." (p. 83). In an attempt to explain these differences, the author listed several possibilities ranging from equipment limitations (restricting movement and vision) to difficulties coping with weightlessness, the stresses of cold, isolation, and anxiety (concerning one's safety).

Baddeley and Fleming (1967) compared the differential effects of diving using oxy-helium versus air breathing systems. The primary objective of this investigation was to examine alternative breathing systems in the hope of reducing the presence of nitrogen narcosis. The performance efficiency of these divers was assessed using two simple tasks (addition tasks and the manual dexterity task used previously by Baddeley). Measurements were taken at two diving depths, 6–10 feet and again at 200 feet. No difference was found between breathing conditions at the 6–10 foot depth. However, at a depth of 200 feet, there was a significant drop in the speed and accuracy of operations (both addition and screw plate tasks). Thus efficiency dropped significantly (i.e., 15–20% worse on addition tasks and 30–45% decrement in manual dexterity) as depth below the surface increased. Baddeley and Flemming suggested that these decrements were likely a result of environmental stressors, perhaps an interaction between the gas mixture (similar to the effect of nitrogen narcosis), and the cold and anxiety of the environment.

Baddeley, DeFiguererdo, Hawkswell, and Williams (1968) also explored cognitive performance during underwater diving. Several measures (digit copying, sentence comprehension, and manual dexterity) were taken at three different depths (surface, five feet, and 200 feet). The authors indicated there was a decrement in efficiency on all three measures (intellectual tasks appeared to be most affected by the nitrogen narcosis and other factors). The degree of impairment was surprisingly similar to that reported under pressure-chamber conditions. This finding was unexpected and contradicts previous research, calling into question the generalizability of such studies (Baddeley, 1966). Baddeley and colleagues attributed the differential effects of underwater diving across these cognitive domains as resulting from environmental stressors, "It seems probable then that anxiety may be the crucial factor in producing the marked performance decrement at depth shown by previous open-sea studies." (p. 163).

Mears and Cleary (1980) also sought to examine the role of anxiety in underwater diving performance. They compared performance at depths of six meters and 30 meters under both day and night time conditions. The 30 meter group differed significantly in performance pattern from that of the six meter group. For example, increased heart rate was observed at the 30 meter depth as was concomitant self-rated anxiety (using the State-Trait Anxiety Inventory). Decrements in manual dexterity were also found at levels that are consistent with previous findings (Baddeley, 1966). In addition, some differences on Raven's matrices, a measure of cognitive ability, were also found at the greater depth. There were no significant differences found in a time-estimation task or the diver's respiration rates.

In addition to examining the effects of underwater diving on measures of psycho-motor performance, other real-world conditions have been employed. Hammerton and Tickner (1969) demonstrated the effect of anxiety and/or fear (preparation for a parachute jump) on perceptual-motor tracking. Performance was poorer just prior to and after parachuting. The authors concluded that anticipatory anxiety and the physiological arousal associated with it were likely sources of the disruption. Hyde, Thomas, Schrot, and Taylor (1997) studied the performance of naval special operations forces under real-world stressors. The authors' goal was to validate a battery of measures within a typical operational context. The specific domains investigated included: strength, visual acuity, hand-eye coordination, endurance, and both fine and gross motor skills. Moreover, measures of manual dexterity were derived from the disassembly and reassembly of a weapon. Hand and arm strength along with endurance were determined by use of a hand dynamometer. Upper body strength was assessed through pull-up performance while lower body mobility, coordination, and strength were assessed using the Harvard Step Test (mounting and dismounting a set of steps). Finally, shooting skills were measured under various conditions for response time and accuracy. Hyde et al. (1997) examined these performance measures under the stress of winter warfare training (cold and austere conditions), under land warfare training (physically demanding activities while sleep deprived), using high-speed boat operations (element exposure), day and night parachute operations (threat and anxiety), and underwater diving operations (element exposure and threat). There was not an absolutely consistent pattern of performance degradation observed across these conditions. However, a general pattern did emerge. For instance, the stress and cold associated with the winter warfare training reduced fine motor skills and hand strength. Similarly, the stress of extended land warfare training tended to reduce fine motor skills as did the environmental stressors of shock, vibration, and exposure to cold during high-speed boat operations. On the contrary, during night-time parachute jumps, most large muscle skills measured were enhanced (grip strength, step test, and pull-up performance). Performance across other measures was not significantly affected. While reducing manual dexterity over time (and increasing cold), underwater diving affected fine motor skills but not large muscle group performance. This finding is consistent with previous investigations (Idzikowski & Baddeley, 1983). Overall, fine motor skills were more susceptible to disruption and degradation than gross motor skills.

While the previous field research paradigms provide an excellent look at the effects of stress in complex environments, the bulk of the research on stress's effects on performance comes from well-controlled laboratory studies. For example, Buck-Gengler and Healy (2001) measured response time and accuracy on a data-entry typing task. They found that as mastery was developed, response time tended to decrease. However, as fatigue set in on the task, accuracy in typing diminished. These findings are consistent with earlier investigations (Fendrich, Healy, & Bourne, 1991; Healy & Bourne, 1995). Evans and Johnson (2000) also examined the effects of stress on a typing task. Their results indicated that exposure to low-intensity noise did not cause a decrement in performance; however, physiological measures of stress indicated greater arousal (elevated epinephrine) and decreases in motivation (negative mood reported). Interestingly, it should be noted that these subjects did not appear to interpret their physiological reactions as signs of stress when interviewed.

Hartley (1981) studied the effects of stress on a motor-pursuit tracking task. He found decrements in performance when subjects were exposed to 95 dB of noise. May and Rice (1971) studied the effects of loud abrupt noise on motor performance. Using a pistol shot, they demonstrated that performance was impaired immediately following the introduction of the noise. The authors reasoned that this decrement was likely due to the startle response observed. Stokes, Belger, and Zhang (1990) found that noise and workload made performance on psychomotor tasks worse. However, they also noted that the effects of these stressors on the Stroop task resulted in an increase in the speed of responses which enhanced performance (possibly facilitated by a tunneling of attention). Schmidgall (2001) reported that the stressors of noise and other environmental factors tended to degrade performance on psychomotor and attention (vigilance/scanning) tasks primarily when the tasks were complex.

Enander (1989) examined the thermal stresses of heat and cold on a test of manual dexterity and strength. The author determined that both tasks were negatively affected by exposure to cold; however, other physical and cognitive domains (vigilance and endurance) were negatively affected by heat. Van Galen and van Huygevoort (2000) examined the effects of time pressure and workload on a perceptual-motor tracking task. They found that these stressors generally resulted in more errors, greater movement variability and greater cursor control pressure on the task. Matthews and Desmond (2002) examined the effects of fatigue and increased workload on tasks of perceptual-motor abilities (a driving task). Driving an automobile requires the management of divided attention and task division. The authors found that fatigue tended to increase errors in heading, steering, and reduced perceptual sensitivity.

Several researchers have investigated the resiliency of psychomotor tasks under stress conditions and concluded that they were unlikely to show much impairment. Theologus, Wheaton, and Fleishman (1974) examined the effect of intermittent noise on performance and found that it tended to degrade various cognitive tasks; however, they concluded that psychomotor tasks appear to be less sensitive to noise effects. Cohen and Weinstein (1981) found similar results under noise exposure. Such findings are intriguing and appear to mirror previously reported results that suggest that well-learned or implicit tasks are more resistant to the negative effects of stress than those requiring active attentional control or higher-order cognitive involvement.

Summary of Findings and Limitations to the Literature

The research literature concerning the effects of stress on perceptual-motor performance consistently shows that these conditions tend to degrade performance. The negative effects of stress on perceptual- and psycho-motor tasks have been demonstrated under a variety of conditions. Most commonly this has been demonstrated using tasks of manual dexterity. Fine motor skills tend to be at greater risk for impairment than gross motor skills. However, compared with higher-order cognitive processes, perceptual-motor skills tend to be less sensitive to various stress effects.

Table 7 provides a sample of research studies on the effects of stress on perceptual-motor performance.

Table 7. Studies showing negative effects of Stress on Perceptual-Motor Performance.

Source	Stress Manipulation	Task	Setting
Baddeley (1966)	Anxiety & fear (diving)	Screw plate task	Real-world
Baddeley, DeFiguererdo, Hawkswell, & Williams (1968)	Anxiety & fear (diving)	Digit copying & Screw plate task	Real-world
Baddeley & Fleming (1967)	Anxiety & fear (diving)	Screw plate task	Real-world
Buck-Gengler & Healy (2001)	Fatigue	Typing task	Laboratory
Enander (1989)	Heat & cold	Manual dexterity	
Fendrich, Healy, & Bourne (1991)	Fatigue	Typing task	Laboratory
Hammerton & Tickner (1969)	Anxiety & fear (parachuting)	Perceptual-motor tracking	Real-world
Healy & Bourne (1995)	Fatigue	Typing task	Review
Hyde, Thomas, Schrot, & Taylor (1997)	Fatigue, cold, heat, workload, time pressure, noise, vibration, etc.	Various military operations	Real-world
Idzikowski & Baddeley (1983)	Diving	Fine motor tasks	Real-world
Lieberman, Bathalon, Falco, Georgelis, Morgan, Niro, & Tharion (2002)	Military combat	Various cognitive tasks	Simulation
Matthews & Desmond (2002)	Fatigue & workload	Driving task	Simulation
May & Rice (1971)	Noise (pistol shot)	Psychomotor task	Laboratory
Mears & Cleary (1980)	Anxiety & fear (diving)	Manual dexterity & cognitive measures	Real-world
Ryan (1962)	Electric shock	Balance on a horizontally pivoted	Laboratory

		platform	
Schmidgall (2001)	Noise (loud/abrupt)	Vigilance & scanning	
Stokes, Belger, & Zhang (1990)	Noise & workload	Psychomotor & Stroop tasks	
Van Galen & van Huygevoort (2000)	Time pressure & workload	Perceptual-motor tracking	Laboratory

Note. R-W = Real-world, L = Laboratory

The Effects of Stress on Judgment and Decision Making

Judgment and decision making constitute distinct processes and outcomes, and investigators differ in their characterization of these two concepts. It can be argued that decision making is the result of judgment—an action-based response. Several authors have attempted to describe and model the process of decision making (Hammond, 1980; Speed & Forsythe, 2002) while others have characterized its role in information processing (Deutsch & Deutsch, 1963; Deutsch & Pew, 2002; Keele, 1973) and as part of the larger cognitive architecture (Leiden, Laughery, Keller, French, Warwick, & Wood, 2001; Neufeld, 1999). Regardless of how these two elements are ultimately defined, they are conceived of by most as related and interconnected. Furthermore, they are typically viewed as an end state culminating from the previous processes discussed (i.e., attention, memory, cognitive appraisal). Are the effects of stress on judgment and decisions more than simply the sum of lower level effects related to attention, memory, and cognitive appraisal? Whether they are a reflection of these previous decrements taken to their logical conclusion or whether they are also subject to further stress effects in their own right is unclear; however, it is clear that judgment and decision making are altered under stress conditions. The research in this area can be divided a number of ways.

In general, judgment and decision making under stress tend to become more rigid with fewer alternatives scanned (Broder, 2000; 2003; Dougherty & Hunter, 2003; Janis, Defares, & Grossman, 1983; Janis & Mann, 1977; Keinan, 1987; Streufert & Streufert, 1981; Walton & McKersie, 1965; Wright, 1974). Furthermore, there is evidence that individuals tend to rely on previous responses (typically when they are familiar and well-learned), regardless of previous response success (Lehner, Seyed-Solorforough, O'Connor, Sak, & Mullin, 1997). Thus, in addition to experiencing greater rigidity, individuals may tend to persist with a method or problem-solving strategy even after it has ceased to be helpful (Cohen, 1952; Staw, Sandelands, & Dutton, 1981). For the sake of organization, I have chosen to present findings about individuals first, followed by research on teams and groups. Consistent with previous sections, the general findings are presented followed by more specific dimensions. Prior to a discussion of stress effects, a brief review of decision theory has been provided.

Theoretical Models of Judgement and Decision Making

Broadbent (1979) asserted that judgment is probabilistic in nature. He employed a signal detection task and noted that when subjects believed that the probability of a signal was high, they were more likely to assert their confidence that the signal was present or absent. Building from Broadbent's theory, Gigerenzer and Selten (2001) argued that decision makers rely on a number of heuristics ranging from the simple to the complex. They theorized that individuals are equipped with an adaptive toolbox that is filled with these different strategies. Accordingly, when faced with a decision, these authors asserted that individuals are wired to employ the most adaptive heuristic available. Perhaps the most well-known heuristic is *take-the-best* (TTB). This model proposes that decision makers, when faced with a decision, search their memories for criterion-linked probability information. Gigerenzer, Haffrage, and Kleinbolting (1991) suggested that this search is bounded by cognitive economy—the search for information is quick, streamlined, and tends to rely on the most valid probabilistic cue separating alternatives. These authors challenged the notion that individuals reasoned from "multiple conditional probabilities," instead opting for a single discriminatory cue. (p. 612).

Broder (2000; 2003) attempted to establish empirical support for this model through the use of an artificial stock market paradigm. Broder (2000) determined that the majority of decision makers relied on this simple heuristic under certain circumstances while choosing other strategies at other times. The author suggested that the operant function in this strategy shifting appeared to be related to the perceived costs incurred with each decision. For instance, when the cost of gathering the additional information was perceived as low, subjects tended to expand their strategy; however, in situations when they perceived the cost of such information as high, they tended to rely solely on the take-the-best heuristic. Although these results have been replicated by others (Newell & Shanks, 2003), Broder (2003) sought to test the model further. Using the same stock market paradigm, the author found similar results. In addition, Broder found a link between a measure of intelligence and heuristic choice. Drawing upon the connection between intellectual ability and working memory capacity, Broder explored these findings in a further experiment designed to test the hypothesis that working memory would be implicated in heuristic choice as well. Broder theorized (as others have before him) that working memory capacity is intimately linked to resource capacity. When individuals are engaged in a high working memory loaded task, their capacity for other information processing operations is likely to be compromised. Broder conjectured that if this is so, then individuals engaged in a decision making task would be more likely to rely on a simple heuristic than a complex one. They would be content with limiting their scan of alternatives in the name of resource management. Although the findings from his second experiment once again indicated that intelligence (as measured by the Wiener Matrizen Test) was the moderating factor in heuristic choice (smarter people choose more adaptive decision making strategies) the results were not as supportive of his working memory hypothesis. Contrary to expectation, there was no link established to working memory load and heuristic choice. This finding is somewhat inconsistent with experiments conducted by Dougherty and Hunter (2003). These authors suggested that individuals tend to make probability judgments by comparing a focal hypothesis with relevant alternatives retrieved from long-term memory. They also concluded that individuals with a large working memory span tend to include more alternatives in their comparison process, and that time constraints probably truncate the alternative generation process so that fewer alternatives are recalled from long-term memory for comparison. This position argues that the complexity of heuristic or strategy employed in decisions may at least in part relate to the amount of time available for the decision.

Individual Judgment and Decision Making

In general, individual judgment and decision making is degraded under stressful conditions. However, just what elements are degraded and in what ways is less clear and is a much more complex issue. It has already been argued that stress can lead to hypervigilance, a state of disorganized and somewhat haphazard attentional processing. Janis and Mann (1977) were the first to formalize these observations under their decision-conflict theory. According to this theory, hypervigilance results in a frantic search, rapid attentional shifting, and a reduction in the number and quality of alternatives considered. Ultimately, this state leads to degraded judgment and decision making. Several investigations have lent support to this theory. Janis, Defares, and Grossman (1983) found this to be true for some decision making tasks under the stress of perceived threat. Keinan (1987) also reported similar findings. He examined performance on a multiple-choice analogies test in order to assess the range of alternatives considered by subjects prior to making a decision. Keinan employed the threat of electric shock as his stress manipulation. He observed that when individuals felt threatened they tended to abandon their previous organized and systematic scan patterns. This resulted in a failure to consider as many alternatives. Furthermore, those that were examined were less systematic in their evaluation of alternatives. The result of this process proved to be a reduction in the quality of their decisions.

Baradell and Klein (1993) designed a study to expand on this previous work by linking the hypervigilant decision making approach to a measure of body consciousness. These authors contended that when individuals experience stressful events they perceive their physiological reactions to these events as representing anxiety. Moreover, these individuals are believed to devote attentional resources toward this anxiety, resulting in a reduction in coping capacity. This lowered capacity diminishes the ability to consider alternatives comprehensively and scan systematically for information related to their judgment of the situation. As a result, Baradell and Klein suggested that individuals who are most sensitive to bodily stimuli are likely to be those who are the most susceptible to poor decision making due to the hypervigilance incurred through resource depletion. Their findings showed individuals scoring high on private body consciousness (sensitivity to internal sensations) performed worse on decision making tasks after experiencing negative life events than those scoring low on the measure of body sensitivity. Individuals scoring low on this measure tended to be rather resistant to the negative effects of stressful events. On the contrary, subjects that scored high on body consciousness tended to scan fewer alternatives prior to making their decisions, they scanned less systematically, and they were more likely to return to previously scanned options. One would conclude from these investigations that hypervigilant responses necessarily lead to poorer outcomes than other strategies. However, some have contended that this is not the case. For example, Driskell, Copper, and Moran (1994) found that subjects who employed a hypervigilant strategy performed better than those who used a vigilant strategy. Hypervigilance did not degrade under time pressure while a vigilant strategy did. The authors concluded that hypervigilant decision styles can be adaptive and effective in some circumstances.

Kastner, Entin, Serfaty, Castanon, and Deckert (1989) employed a naval combat simulation task in their examination of the effects of task difficulty on decision making processes. These authors designated subjects as anti-submarine warfare commanders charging them with the task of friend or foe determinations. Decision makers were provided access (at a cost) to either a human consultant or a probe sensor. The levels of expertise of these two agents varied as did their costs (time penalties). As reported by Entin and Serfaty (1990), the researchers developed an optimal model of information search through which they tried to determine, "…under what circumstances decision makers should stop gathering information and start making decisions, and under what conditions decision makers should seek processed information (consultant opinions) rather than raw information (probe measurements)." (p. 4). Their results indicated that subjects tended to seek more information than was optimal and that such information tended to be preferentially sought from consultants who had already processed the data themselves. This was true even in cases when the cost associated with seeking the information clearly outweighed any potential benefit. In an extension of this work, Entin and Serfaty (1990) explored a very similar paradigm. In their experiment, subjects were under the dual "stress" of time pressure and a secondary task that intruded on their primary decisions. Task difficulty varied across workload levels, the discriminability of enemy versus friendly submarines, the cost to implement the consultant or the probe, and the level of expertise of the consultant (measured in error rate levels). Entin and Serfaty found that decision makers tended to seek out more information in difficult versus easy discrimination tasks, and they typically followed a rational cost-benefit rule in their decisions. Cost information was determined to be the most important moderator, and under difficult decisions they typically preferred the easier-to-process opinion of the consultant. This was particularly the case as time pressure and workload increased.

Sinclair and Mark (1995) explored the effects of mood state on judgment accuracy. There is a large literature that supports the notion that mood moderates differential processing strategies. This assertion has already been substantiated for anxiety and threat in terms of attentional bias.

> …subjects in positive states, regardless of arousal level, appear to make less effortful and less detail-oriented decisions that result in error, relative to those in negative states. Negative affective states, regardless of arousal level, appear to result in more effortful and systematic processing that can lead to greater accuracy in decision making, relative to positive affective states. (p. 430)

Sinclair and Mark suggest that in cases when systematic and careful processing of information is related to enhancing performance, sad individuals should be more accurate in their problem solving than happy individuals. To test this hypothesis, the authors devised three experiments. In their first experiment the authors employed a mood induction procedure where subjects were asked to read 60 statements (elated, neutral, or depressed) and then concentrated for two minutes on an event in their personal lives that caused them to feel similar to the mood statements. Following this induction phase, subjects completed a mood inventory. After this measure was complete, subjects were asked to examine and estimate the correlation coefficients of nine different scatter plots. The authors conducted a mood-manipulation check that confirmed the effectiveness of the mood-induction procedure. Their results indicated that subjects with more positive moods were the least accurate in judgments while those with neutral or negative moods were the most accurate.

The authors noted that any conclusion that suggested mood was the operant element would be difficult as the presence of physiological arousal confounded such a determination. Accordingly, the author's second experiment implemented separate affective and arousal induction items (Velten serenity and anxiety) in addition to the previous positive, negative, and neutral mood items. Following completion of a mood measure, subjects were once again shown a series of scatter plots and asked to estimate their corresponding coefficients. Additionally, each subject was asked to rate his/her level of effort and provide a description of the strategy employed in the exercise. The authors performed a principal axis factor analysis which ultimately revealed two main factors, arousal and affect, accounting for 29% and 47% of the variance respectively. The authors found that regardless of arousal level, subjects experiencing negative affect tended to access more information as well as more helpful information in their assessment of the scatter plot relationships. On the contrary, subjects with more positive mood states tended to approach the task with less effort and less time than those with negative mood ratings. This general trend appeared to be most characteristic of correlations that were weaker than those that were stronger. Thus, in less ambiguous estimations, mood was less of a factor in determining performance outcome.

Finally, the author's third experiment replicated the design of the first two while adding a direct manipulation of processing strategy. Specifically, they instructed half of the subjects to engage in a thoughtful and systematic analysis of the task—indicating that strong performance would increase the class extra credit received by their participation. The results of this approach indicate that direct manipulation of processing strategy is possible and that the outcome mimics that of induced positive versus negative mood state. The authors concluded that processing strategy may moderate the effects witnessed as a result of mood state. Thus, subjects in positive moods may be less likely to use the kind of systematic and detail-oriented processing strategy that motivated neutral-mood individuals employ. The authors caution that heuristic use and processing strategy are likely to be task and situation dependent and that arguing the benefits of sad or neutral mood states over positive mood states in terms of judgment and decision making is likely to be an oversimplification of the findings.

These are not the only investigations to link affect and decision making. Dreisbach and Goschke (2004) reviewed the research literature addressing the relationship between positive affect and various cognitive processes. They concluded that positive affect tends to increase cognitive flexibility, verbal fluency, flexibility in decision making, shifts in heuristic use, and enhances the activation of remote associates from memory. Calvo and Castillo (2001) examined the effect of negative affect on decision making and found that anxious individuals were more likely to make inferences that were mood-based than individuals who were not anxious. This finding is clearly related to mood-related attentional biases as well as the mood-congruent memory-recall literature previously reviewed.

Many of the putative stressors described previously have been studied for their effects on judgment and decision making. For instance, Rotton, Olszewski, Charleton, and Soler (1978) found that the stress of noise reduced individuals' ability to distinguish between social roles, which resulted in greater difficulty in social judgments and decisions. Soetens, Hueting, and Wauters (1992) found that fatigue degraded individuals' performance on complex decision tasks but not on more simplistic judgments. Yamamoto (1984) examined the stress caused by a simulated fire and found that such conditions tended to result in degraded cognitive performance related to judgment and decision making on a variety of laboratory tasks. Several groups have investigated the effect of time pressure on judgment and decision making. The results of these investigations have been consistent and negative (Stokes, Kemper, & Marsh, 1992; Wickens, Stokes, Barnett, & Hyman, 1991; Zakay & Wooler, 1984). For example, Ben Zur and Breznitz (1981) used a gambling paradigm in their examination of decision making strategies. These authors found that decision makers under time pressure tended to make lower risk choices and spend more time viewing negative dimensions related to their decisions. Rothstein (1986) also examined decision making under time pressure and found that subjects were able to implement sound decision policies, but their behavior was more erratic than when time for their decisions was not as limited.

Speier, Valacich, and Vessey (1999) investigated the effects of interruptions on individual decision making noting "interruptions were found to improve decision-making performance on simple tasks and to lower performance on complex tasks. For complex tasks, the frequency of interruptions and the dissimilarity of content between the primary and interrupted tasks was found to exacerbate this effect." (p. 337). The authors argued that interruptions make information overload worse by reducing the amount of time one has to spend working the problem, which in turn leads to feeling time pressured. This creates both capacity, too much information to process, and structural, inputs that are occupying the same physiological channel, interference (i.e., monitoring two visual displays at once). Moreover, interruptions also place greater demand on the cognitive processing system. For example, information that is forgotten due to overload requires further resources to re-process or simply never gets encoded.

Ruffell Smith (1979) investigated the effects of increased workload on flight crew performance. Examining 20 three-person flight crews from a major civil aviation transport carrier, Ruffell Smith subjected crews to a series of flight simulator scenarios under various workload conditions (i.e., routine to abnormal scenarios). Flight crews were fitted with physiological monitoring equipment during their observations. Data was recorded across five dimensions to include: observer's comments (a running commentary concerning activities and errors), crewmember heart rate, paperwork or documentation regarding each flight, flight deck communications, and aircraft parameters. Crews initially flew an uneventful leg followed by a period of high workload (i.e., mechanical malfunctions, fuel load and weight issues, weather conditions, etc.). Following this period of flight, crews experienced a relative calm which ended in a more complicated landing sequence including a hand-flown ILS (Instrument Landing System) approach and a three-engine landing. Upon analysis, the author noted that a series of errors were made. These were categorized into several main types including those considered to be: navigational, communication-related, systems errors, flying errors, tactical-decision errors, and difficulties in crew integration or resource management. The results of this study indicate that periods of increased workload, even those considered to be part of normal flight operations, increased the frequency and volume of errors. In addition to a listing of errors and error frequencies, Ruffell Smith also provided a narrative account of how errors occurred during different phases of the flights. The author noted that procedural errors tended to be related to poor coordination among crew members while under stressful conditions. The greatest deviations in heart rate appeared immediately following take-off and landing procedures. Moreover, heart rate lability was also associated with the pilot flying as opposed to the pilot not flying in each scenario—when at the controls of the aircraft, pilots tended to experience a rise in their heart rates. It was also observed that reaction time was increased significantly for captains when faced with the decision to shut down an engine in flight. However, this was typically only when they were at the controls. The author concluded that numerous human factors issues remained unaddressed in airline operations, highlighting problems that ranged from instrumentation and ergonomics to checklist design.

Wickens, Stokes, Barnett, and Hyman (1991) examined the effects of stress on pilot decision making. These authors highlighted the earlier work of Broadbent (1971) and Hockey (1986) as a foundation for current perspectives on how stress affects information processing. They cited three main effects: 1) a reduction in cue sampling, 2) a reduction in the resource-limited capacity of working memory, and 3) when time is reduced, a speed-accuracy trade-off in performance outcome. In their investigation, Wickens and colleagues implemented the computer-based pilot decision program, MIDIS. Pilots were tasked with viewing a computer screen containing operating instrumentation and a text box that described various decisions during the course of a simulated flight. In an initial study, expert pilots were found to make similar decisions to novice pilots, though they tended to be more confident in their decisions. In a second experiment, pilots were asked to engage in a series of flight scenarios using the MIDIS system. Subjects were also asked to manage a concurrent task (the Sternberg memory search). Prior to initiating the flight scenarios, pilots were presented a four-letter memory set for memorization and then later asked to indicate when they recognized one of the letters appearing on the screen (during the flight simulation). A number of target and non-target letters were presented during the simulation. In addition, an annoying tone signaled after responding to the letters. If the pilots were correct in their recognition, this noise lasted only two seconds, if incorrect it continued for 12 seconds. The subjects were further motivated to accomplish the secondary memory task through a financial reward, the better the performance, the more money guaranteed. The results demonstrated that the authors' motivational manipulations were effective. Furthermore, it was determined that the stress conditions presented alongside the MIDIS program did degrade decision making. These authors found that decisions requiring the activation of declarative knowledge were poorer than those that did not (procedural knowledge), but that they were made more rapidly and with more confidence.

Ozel (2001) examined how fire fighters process environmental information used for the decision to exit a fire. Under time pressure and the threat of fire, Ozel asserted that when slightly "stressed," one's ability to determine the best time to exit was likely to be enhanced, while under high levels of stress there would probably be a restriction in the range of cues attended and a distortion of information processing. He suggested that the result was likely to be a decrement in performance. Thus, based on a review of Easterbrook's model of attentional narrowing and its impact on various information processing systems, Ozel posited that judgment and decision making would be degraded under stress conditions typical of fire-fighting situations.

The Role of Experience in Judgment and Decision Making

One's experience level or familiarity with a type of decision task has been found to be related to the quality of their decision (Shafto & Coley, 2003). Several domains of expert decision making have been examined, most frequently fire fighting (Klein, 1989; Klein & Klinger, 1991; Taynor, Crandall, & Wiggins, 1987), military operations, and aviation (Hutton, Thordsen, & Mogford, 1997; Klein & Thordsen, 1991; Stoke, Kemper, & Marsh, 1992). For example, Klein observed the decision making process of fire-ground commanders using a "think aloud" approach to his investigation. He determined that experts in this kind of analysis tended toward a systematic and sequential strategy versus that adopted by novices, who evaluated conditions concurrently. Klein suggested that experts may be able to draw upon large stores of information from their long-term memory to assist them, possibly recognizing patterns with which to compare current situations with previous outcomes. Stokes, Kemper, and Marsh (1992) argued for this sort of schema-based evaluation in expert aviators as well. Shafto and Coley (2003) contend that experts make decisions on the basis of, "causal/ecological reasoning steeped in the context of the respective environs" as opposed to the novices, who rely on, "more decontextualized similarity-based reasoning." (p. 642). Stokes (1995) further examined pilot performance on an aeronautical decision making task and found that novice pilots made poorer decisions than expert pilots and their decision making was further degraded under stress while expert pilots decision making was not. This is certainly consistent with previous findings that have causally linked a pilot's risk of being involved in an airline accident and their experience level (Kornovich, 1992; Li, Baker, Grabowski, & Rebok, 2001)—as expected, experienced pilots are less likely to be at risk than less experienced pilots.

Similarly, Wiggins and O'Hare (1995) explored the relationship between pilot experience and decision making strategies. They compared three groups of pilots: inexperienced, intermediate, and experienced (measured in overall flight time). Each pilot was provided a series of tasks to include measures of general problem solving ability, a syllogistic reasoning task, and a set of aeronautical decision scenarios calling for weather-related aeronautical determinations. Their investigation suggested that the more experience a pilot had, the more effective his or her cognitive strategy in making decisions was likely to be. Additionally, experienced pilots tended to visually search fewer screens of information, return to previously scanned information screens less often, and spent less time examining these screens than novice pilots. Experienced pilots also tended to take less time in making aeronautical and weather-related decisions. One of the most insightful findings of this study was that the potency of expertise appeared to be related to task-specific domains. That is to say, although experience as a pilot did aid in differentiating experts from novices in decision making, expertise in weather-related decisions as a pilot was the most predictive variable. Thus, expertise in and of itself helps, but it may be that task-specific experience is most relevant to time-critical decision making. This finding highlights the potential importance of realistic emergency and abnormal situation training, for in no other way can novice operators (regardless of the industry they represent) safely garner emergency decision making expertise.

Lansdown (2001) examined the differences in novice and expert drivers. He found that experts tended to be more efficient in their attentive processing. Specifically, experts relied more on peripheral visual cues to maintain lane position as compared to novices who relied heavily on foveal fixations. This finding led Lansdown to suggest that experts have more attentional resources to devote to other events or situations than novices due to this simplification or paring of tasks. This conclusion is well-supported by other research on the differences in resource management by experienced versus novice operators (Burke, 1980; Doane, Woo Sohn, & Jodlowski, 2004; MacDonald & Lubac, 1982; Stokes, 1995). These investigations into expertise provide at least one explanation for why stress tends to degrade novice performance and not expert performance differentially. For example, expertise affords the operator greater resources to devote toward other tasks through the proceduralization and automation of their performance.

Team Judgment and Decision Making

There is an expanding literature concerning team or group decision making. Historically, research has maintained a focus on the individual in terms of human performance. Examinations of the human-machine interface and methodology used to assess cognitive task analysis is all but exclusively oriented toward the individual (McDermott, Klein, Thordsen, Ransom, & Paley, 2000). Accordingly, various research groups have developed models designed to replicate the cognitive requirements and profile limitations of human teams (MacMillan, Paley, Levchuk, Entin, Freeman, & Serfaty, 2001). McBride (1988) examined three-member teams under time pressure and mental workload (increasing the rate of information presented to the teams). Each team was observed while performing a dynamic group-choice task. Teams that were provided a set of useful decision heuristics tended to report experiencing less stress and also performed better than teams who were not provided useful heuristics. The degree of stress created by time pressure was clearly related to the degree of effect suffered. Thus, teams performed worse as time pressure to make their decisions increased, regardless of heuristic choice.

Effective or adaptive teams tend to shift strategies under stress. Specifically, their use of explicit coordination appears to shift to implicit coordination, subsequently enhancing performance (Entin & Serfaty, 1990; Entin, Serfaty, & Dekert, 1994; Entin, Serfaty, Entin, & Dekert, 1993; Serfaty, Entin, & Johnston, 1998). Bowers, Salas, Asberg, Burke, Priest, and Milham (2002) found this to be true in experiments using a high fidelity simulation under time pressure and mental workload. Using an artificial stock market game, Broder's (2003) results also suggested that most participants shifted strategies in an attempt to adapt to the situation. Entin and Serfaty's (1999) examination of teams indicated that they tended to draw on shared mental models of their situation and task. This has previously been shown to be of value in the performance of aircrew (Orasanu, 1990). This strategy facilitated their ability to shift from explicit to implicit coordination, thereby reducing coordination "overhead" (the typical costs incurred by explicit strategies). These authors subsequently designed team-training procedures to teach teams to adapt to high-stress situations by improving their coordination strategies. Investigations have also found the inverse of this phenomenon, whereby less-adaptive teams lose implicit coordination when under stress, reverting to explicit strategies.

Driskell, Salas, and Johnston (1999) examined social behavior in team decision making. These authors noted the common finding of Easterbrook's attentional narrowing hypothesis and proposed that it could be extended to the group-process level. Highlighting recent examples from the airline industry whereby an aircrew's performance as a team was causally linked to both positive and negative outcomes, Driskell et al. suggested that stress can reduce group focus that is necessary to maintain proper crew coordination and situational awareness. Using Navy personnel, the authors constructed a computer-based simulation of a naval decision task. Subjects were placed in teams of three, interacting over a computer network at varying levels. Their tasks consisted of the classification of craft (sub, surface, or air) with an assessment of their status (military or civilian) and intentions (friend or enemy). Stress was manipulated across auditory distraction, task load, and time pressure. Their results indicated that groups lost team perspective under stress and that they were more likely to shift to individualistic self-focus than maintaining their group team-focus. The authors suggest that this occurs when, "…social or team cues are marginalized as attention is narrowed under stress…." (p. 300). In a related line of research, several investigators have concluded that time pressure increases the level of cooperation between groups in negotiation because it facilitates concession making; however, it has been noted that this may also interfere with the development of integrative agreements due to forced cooperation (Pruitt, 1981; Pruitt & Carnevale, 1982; Rubin & Brown, 1975).

In addition to a shift to implicit over explicit strategy, various research results point to task or load-shedding as another adaptive strategy. This form of task simplification has been studied in a variety of contexts. Davis (1948) studied the effects of fatigue and continuous flying operations on pilots. He observed that, over time, pilots reduced their visual scan toward peripheral instrumentation opting for greater focus on instruments used in the central task of flying. Bursill (1958) replicated these findings on laboratory tasks. Welford (1973) further reviewed these earlier investigations into task-shedding and equated them to social attempts at load-shedding used by the elderly. Rothstein and Markowitz (1982) investigated task-shedding under the stress of time pressure. In their investigation they provided subjects with seven seconds to decide which of two sets of numbers had the largest mean. They found that subjects tended to simplify the task under the pressures of limited time. The most common approach was to use the larger sum as the indicator, even when this strategy was inaccurate. Raby and Wickens (1990) also examined task-shedding strategies in an aeronautical decision making task. In their experiment, pilots reduced their workload when task saturated and stressed. This tended to occur in expected directions. They initially dropped tasks that fell into the "can do" category, followed by those considered as "should do" items and lastly by more critical tasks falling into the "must do" category.

Strategy-shifting and task-shedding often result in economical savings in cognitive resources as workload increases. Sperandio (1971) explored this strategy in his examination of Air Traffic Controllers (ATC). He found that controllers tend to exercise a regulating effect on their workload through strategy shifting. Observing ATC operations, Sperandio found that controllers under increasing workload conditions (measured by traffic load) tended to shift from a direct approach strategy (data needed to verify and possibly achieve separation between aircraft) to a standard approach strategy (data concerning aircraft performance not needed for separation of aircraft). This shift from direct to standard approaches provided less precise but adequate information. In short, "when the traffic level increases, the controller reduces the number of variables that he must process." (p. 574). For example, during periods of low traffic (low workload) controllers tended to take into account several data points (performance data, flight levels, geographical information, etc.), but when traffic conditions increased significantly, just flight levels were attended to and processed. Sperandio concluded that controllers are economizing their workload with a shift in strategy or method, reducing any redundant information or non-essential information from being processed. These findings are consistent with previously reported research on expert versus novice decision making (Burke, 1980; Davis, 1948; Klein, 1989; Lansdown, 2001; MacDonald & Lubac, 1982; Stokes, 1995).

Summary of Findings and Limitations to the Literature

The research literature concerning the effects of stress on judgment and decision making demonstrates that both individual and team processes are degraded. Many of the putative stressors described previously have been shown to negatively affect these processes (e.g., noise, fatigue, physical or emotional threat, etc.). The ways in which this occurs are diverse. Stress can lead to hypervigilance, a state of disorganized and somewhat haphazard attentional processing. This condition often results in a frantic search, rapid attentional shifting and a reduction in the number and quality of alternatives considered. As fewer alternatives are considered, there is a recursion to previously sampled possibilities. Individuals tend to rely on these previous responses regardless of their previous response success. Thus, in addition to experiencing greater rigidity, individuals may tend to persist with a method or strategy even after it has ceased to be helpful. This assumes that the previous strategy or approach is well-learned.

Affect or mood has also been implicated in judgment and decision making. Individuals experiencing negative affect tend to access more information in general as well as more helpful information in their assessment of situations. What has been termed "depressive realism" in the past has found some support in this regard. The inverse of this assertion appears also to be true. Those experiencing positive mood states tend to approach tasks with less effort and less time. This trend appears most characteristic of decisions or judgments that are made when the task or conditions are ambiguous. Thus, individuals in positive moods may be less likely to use systematic and detail-oriented processing strategies in their decision as compared to individuals who are experiencing a negative mood.

Effective or adaptive teams tend to shift strategies under stress. This often takes the form of a shift from explicit coordination toward implicit coordination, subsequently enhancing performance. This strategy has been suggested to reduce coordination overhead or the typical costs in time, resources, and effort that teams using explicit strategies alone incur. The opposite is true for less adaptive teams under stress. These groups tend to lose implicit coordination and fall back to explicit, on-line control strategies. The result can be a heavy cost in resources and ultimately decrements in performance. This phenomenon has also been described as a loss in team perspective. In this regard, teams under stress may lose their shared mental models and their collective comprehension (awareness of each other's efforts), shifting to an individualistic self-focus. Although it has not been definitively determined, teams that share common mental models are believed to be those that are able to shift from explicit to implicit coordination.

In addition to strategy shifting, various research results point to task or load shedding as another adaptive strategy. This form of task simplification has been studied in a variety of contexts and has been characterized as economizing workload with a shift in strategy or method that reduces any redundant information or non-essential information from being processed. This type of resource management seems to happen logically and/or systematically at first (paring tasks appropriately) but may result in less-organized and less-reasoned shedding as workload and stress increase to dramatic levels.

The reader will note that decision making has frequently been studied under simulation or real-world-like environments. This has been the case more often than in previous cognitive processes examined. It is likely that the complexity of judgment and decision making forces this type of approach. But more restrictive approaches are highly desirable, in order to augment the study of decision-making under naturalistic settings. Table 8 provides a sample of research studies on the effects of stress on judgment and decision making.

Table 8. Studies showing negative effects of Stress on Judgment and Decision Making.

Source	Stress Manipulation	Task or Outcome	Setting
Baradell & Klein (1993)	Negative life events & state anxiety	Analogies task	Laboratory
Bar-Tal, Raviv, & Spitzer (1999)	Negative life events	Cognitive structuring & decision tasks	Real-World
Ben Zur & Breznitz (1981)	Time pressure	Gambling tasks	Laboratory
Bowers, Salas, Asberg, Burke, Priest, & Milham (2002)	Time pressure & workload	Explicit to implicit shift	Simulation
Broadbent (1979)	Noise	Signal detection	Laboratory
Broder (2003)	Workload	Heuristic choice	Laboratory
Bursill (1958)	Fatigue (flying)	Task-shedding	Laboratory
Calvo & Castillo (2001)	Anxiety	Inferences	Laboratory
Cohen (1952)	Stress	Greater rigidity, fewer alternatives considered	Laboratory
Davis (1948)	Fatigue (flying)	Task-shedding	Simulation
Dorner (1990)	Stress	Prone to ballistic DM style	
Driskell, Copper, & Moran (1994)	Time pressure	Hypervigilant style	Simulation
Driskell, Salas, & Johnston (1999)	Stress	Implicit to explicit shift	Simulation
Entin & Serfaty (1990)	Time pressure & workload	Simplified heuristic	Simulation
Entin & Serfaty (1999)	Stress	Explicit to implicit shift	Simulation
Kastner, Entin, Serfaty, Castanon, & Deckert (1989)	Task difficulty	Strategy shift	Simulation
Lehner, Seyed-Solorforough, O'Connor, Sak, &	Time pressure	Most familiar heuristic	Simulation

Mullin (1997)			
McBride (1988)	Time Pressure	Heuristic training helped	Laboratory
Ozel (2001)	Time pressure & threat	Decision to exit fire	Review
Pruitt (1981)	Time pressure	Facilitates concession making	Review
Pruitt & Carnevale (1982)	Time pressure	Facilitates concession making	Review
Raby & Wickens (1990)	Workload (flying)	Task-shedding	Simulation
Rothstein (1986)	Time pressure	Erratic DM style	
Rothstein & Markowitz (1982)	Time pressure	Task-shedding	Laboratory
Rotton, Olszewski, Charleton, & Soler (1978)	Noise	Social role distinction	Laboratory
Rubin & Brown (1975)	Time pressure	Facilitates concession making	Review
Ruffell Smith (1979)	Workload	Poor CRM & explicit to implicit shift	Simulation
Serfaty, Entin, & Johnston (1998)	Workload	Explicit to implicit shift	Simulation
Soetens, Hueting, & Wauters (1992)	Fatigue	Complex decision tasks	Laboratory
Sinclair & Mark (1995)	Mood	Correlation coefficient estimations	Laboratory
Sperandio (1971)	Workload (ATC)	Task simplification	Real-world
Staw, Sandelands, & Dutton (1981)	Stress	Greater rigidity, fewer alternatives considered	Laboratory
Stokes (1995)	Stress & anxiety	Novice pilot DM	Simulation
Stokes, Kemper, & Marsh (1992)	Time pressure	Decision making	Simulation
Streufert & Streufert (1981)	Time pressure	Greater rigidity, fewer alternatives considered	Laboratory
Walton & McKersie (1965)	Time pressure	Greater rigidity, fewer alternatives considered	Laboratory

Welford (1973)	Social situations (elderly)	Task-shedding	Review
Wickens, Stokes, Barnett, & Hyman (1991)	Time pressure, noise, & financial risk	Vigilance & attention	Simulation
Wright (1974)	Time pressure	Greater rigidity, fewer alternatives considered	Laboratory
Yamamoto (1984)	Threat of fire		Laboratory
Zakay & Wooler (1984)	Time pressure	Buying decisions	Laboratory

The Effects of Putative Stressors on Performance

Putative stressors such as workload (i.e., concurrent task management, task switching, time pressure), heat and cold, noise, and fatigue have already been discussed in part during previous sections (e.g., attention, memory). However, there are large bodies of literature that focus directly on each of these variables individually. In the preceding sections, I briefly review the research that supports major conclusions about each "stressor's" role in affecting performance. Portions of this review have been included in previous sections as appropriate; however, additional research that addresses these stressors directly is also presented.

There is significant inconsistency among researchers concerning the direct and indirect effects of various putative stressors. Direct stress effects are those incurred by the task load alone irrespective of any psychological stress that may also be generated. Accordingly, indirect stress effects are those that evolve out of psychological factors associated with the task load demands. There is a fine line that separates these two, and they can be indistinguishable at times. This fact has made their separation and measurement particularly difficult. There are several issues at the heart of the inconsistencies found in the literature. For example, is the application of some task demand (i.e., workload or time pressure) an application of stress? Many would argue that it is while others would contend the contrary. Proponents of the former typically offer one of two arguments. The first argument states that stress is a term that can be applied to any demand on a system. Therefore, any task that requires mental resources qualifies as a stressor—it places a demand on the system. This argument meets the criteria of early stress definitions (stimulus-based approaches); however, it is no longer as accepted given the widespread belief that stress is transactional in nature. The second argument proposes that demands incur a psychological cost in addition to their direct effects. That is to say, these demands trigger a psychological response such as frustration, anxiety, or psychological discomfort. This response often contains both physiological and mental components that vie for resources. In this way, stress acts as a secondary workload factor drawing resources away from the primary demand, devoting them instead to secondary psychological processes.

On the other hand, a compelling argument can be made that workload is a demand that does not require, nor regularly incur, a secondary psychological cost. In applying the stated definition of stress—the interaction between three perceptions: a demand, an ability to cope with that demand, and the importance of being able to cope (McGrath, 1976), it's difficult to see how demand characteristics alone qualify as stressors. For example, in some circumstances time pressure and/or workload would trigger anxiety or frustration that might further distract or interfere with performance. However, it is not clear that this would necessarily be so in most, let alone all, situations.

If we agree that subjective experience and specifically cognitive appraisal (a transactional model assumption) is elemental in defining stress, then one must assume it plays a significant role in answering questions about whether workload, time pressure, or other putative stressors carry both direct and indirect effects. Does this suggest that when a demand is deemed stressful or upsetting it is necessarily a stressor, regardless of the objective outcome? If an increase in workload does not impair performance yet is viewed as stressful by the operator, does this indicate that it should be considered a stressor? Reasonable arguments can be made to support both positions, and the research literature, in its current state, is a reflection of this fact. As the reader has already observed, several researchers have attempted to side-step this issue by relying on descriptions of task load alone, ignoring the potential accompanying psychological stress. In doing so, they have circumvented a direct discussion of stress and its role in performance degradation or enhancement. However, in leaving this issue unaddressed, these authors have left the reader to infer a stress effect, correctly or not. I have not attempted to resolve this issue but to make the reader aware of it. At the end of this review I attempt to provide a conceptual framework that helps organize data and concepts that I hope provides more coherence than is apparent in the literature.

The Effects of Workload (Work Volume, Concurrent Task Management, and Task Switching)

Early views of stress treated the concept and the human organism in mechanistic terms (Cannon, 1932; Selye, 1950). Stress was frequently viewed as present when demands outweighed resources. The resulting “strain” on the system was seen as a stress effect. Later theorists included a cognitive component to this definition yet stress was still conceived as an imbalance between environmental demands and the organism’s capability to adequately respond to those demands (Lazarus, 1966). This type of simplistic dichotomy lent itself to an interpretation of workload and other variables as “stressors.” For instance, it has been established that increased work volume requires greater resources to sustain performance. According to earlier views of stress, this fact alone draws the parallel between the two concepts. Although there is far from universal acceptance of this connection, many in the research community today still consider factors such as workload, stress-related.

Although some have resisted the temptation to connect workload and stress, instead relying on descriptions of the task demands alone (Hancock & Desmond, 2001), this has proven difficult given the divergence among the research community. For example, Parasuraman and Hancock (2001) drew a distinction between workload and task load, asserting that task load was the environmental load on the organism while workload was the experience of that loading by the organism as it attempted to adapt accordingly. These descriptions are reminiscent of the troubled distinction between direct and indirect stress effects. Readers are likely to be confused by the inconsistencies among researchers as one investigation’s task loading is another’s stressor. The following discussion of workload elements has been provided in light of the divergence that exists among researchers in this area. The reader should note that this reviewer found little, if any, discussion in previous reviews or in the primary literature that provided a validation account for the connection between putative stressors and psychological stress.

Most human interactions in the world involve dynamic and complex management of multiple tasks. This is certainly true of human-machine interactions. Thus, it is not insignificant that a large portion of the human performance literature has historically examined single putative stressors, isolated from their environments. Unfortunately, as valuable as such studies are to our collective understanding of various processes and their relationships, they fail to match the character of the world we live in. Because of this, research that examines multitask performance is of particular interest. Much of this research literature has already been reviewed under previous sections of attention and memory; however, studies directly related to concurrent task management not previously addressed are reviewed below.

In general, concurrent task management results in degraded performance on either the primary or secondary task (Hitch & Baddeley, 1976; Kahneman, 1975; Neisser & Becklan, 1975; Shaffer, 1975). It should be noted that among studies in the experimental literature, discerning a primary from a secondary task is somewhat arbitrary. Simply stated, within the limited resources model, multiple tasks divide available resources between themselves and under high workload or stress conditions, there tend to be insufficient resources to concurrently manage both tasks. Therefore, one, if not both tasks (having received less than optimal resource devotion), suffers. While real-world settings may in some circumstances afford natural primary task and secondary tasks, often times these designations are merely a laboratory convenience more than a reflection of the naturalistic design.

The concept of capacity and the presumption of limited resources has been the most popular explanation as the intervening variable in dual-task performance decrements (Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975). Similarly, earlier models of single-channel information processing (Kerr, 1973) have recently made way for the assertion of more complex system explanations. For example, in contrast to Broadbent (1958) and Treisman's (1969) early selection theory which postulates a single-channel information processing bottleneck in structural theory (occurring at the point of perception), Wickens and Dixon (2002), based on their exploration of navigational flying tasks, proposed three theories of concurrent task demands, single channel, single resource, and multiple resource. The authors found the most convincing support for a multiple-resource model. Wickens (1991) was one of the first to introduce a multiple resources model, choosing to illustrate the model using a concurrent task management example. This author suggested that three possible factors were engaged in concurrent task management performance outcomes. The first was confusion, which he defined as a condition where similar tasks often interfere with performance while more distinct tasks degrade performance less often. The second potential outcome he coined cooperation. The cooperation between task processes can be seen when high task similarity yields combined results (i.e., tracking a ball as you prepare to hit it with a racquet). Finally, he suggested that there can be competition between demands. Competition for task resources, specifically resource allocation to one task versus another, results in diminishing resources from the other task(s) being managed. Wickens has argued that timesharing (cooperation) improves between tasks to the extent that they use separate versus shared resources.

The research reviewed here predominantly adheres to the notions of confusion and competition between concurrent tasks. Driskell, Mullen, Johnson, Hughes, and Batchelor (1992) performed a meta-analysis of studies investigating dual-task performance. They reported a relatively consistent finding (over a variety of stressors to include thermal, noise, time pressure, etc.) that performance on the primary task tends to suffer when individuals attempt to accommodate a secondary task (a moderate effect size was noted). The authors found that the more similar the two tasks, the greater the interference and the worse the primary task performance. Thus performance did not degrade to the same extent when attempting to manage dissimilar tasks. Boggs and Simon (1968) and Finkelman and Glass (1970) observed similar differential effects with exposure to noise. McLeod (1977) determined that performance on a tracking task was worse under conditions of high response similarity, when both responses were manual as compared to conditions of low response similarity (one manual, one verbal). This seems consistent with the idea that less confusion or interference occurs as task characteristics diverge.

Allport, Antonis, and Reynolds (1972) examined dual-task performance in listening and reading tasks. They found that subjects who attempted to verbally shadow prose passages while learning auditorily presented words performed worse than when learning visually presented words. Sullivan (1976) enlisted subjects to perform dual auditory tasks, shadowing and target detection. Each task was presented to a different ear which resulted in an increased difficulty in performance of the shadowing task, in turn leading to fewer target detections. Concurrent task management does appear to be easier (performance improves) when tasks are dissimilar than when they are similar (Treisman & Davies, 1973). Wickens (1980) theorized that two tasks with similar processing demands will interfere with each other more than tasks with different processing demands which may account for these findings.

It should be well established in the mind of the reader by this time that dividing attention between tasks reduces the attentional resources available to devote to either task. In such cases when the recall or recognition of information is examined, this division frequently results in a decrease in memory recall and recognition. The mechanisms under which this occurs are somewhat obscured at the present, but they are becoming clearer. Baddeley, Lewis, Elderidge, and Thomson (1984) have demonstrated that dividing attentional resources tends to negatively affect the encoding of information into memory. Naveh-Benjamin, Guez, and Marom (2003) and Craik, Govoni, Naveh-Benjamin, and Anderson (1996) have proposed several different mechanisms for this occurrence. From this list have emerged the two strongest candidates, the time availability hypothesis and the elaboration hypothesis. The former suggests that divisions in attention lead to reductions in the time available to process incoming stimuli (due to time devoted to a secondary task). The latter hypothesis proposes that information is coded with less elaboration and depth when attentional resources are divided. Naveh-Benjamin et al. (2003) explored a third hypothesis, the associative deficit hypothesis, which suggests that divided attention disrupts the coherence between associated units of information during encoding. However, they failed to find adequate support for this explanation in their own examination of the mechanism.

While the general findings concerning concurrent task management are compelling, in some instances this management does not lead to degraded performance on either task. Several authors have examined the accuracy in simultaneously detecting tones and lights and found little interference effects (Eijkman & Vendrik, 1965; Moore & Massaro, 1973; Tulving & Lindsay, 1967). Similarly, dual-task performance can be maintained across both tasks when they are well-learned (Spelke, Hirst, & Neisser, 1976). Hirst, Spelke, Reaves, Caharack, and Neisser (1980) examined this hypothesis by asking subjects to read aloud prose while taking dictation. These authors tested individuals initially and after 50 hours of practice and found that highly practiced tasks can be performed jointly with little interference. Schneider and Detweiler (1988) suggested that automatic and/or controlled processing theory could be used to account for such observations.

Undoubtedly, the degree to which performance is affected seems likely to be related to the difficulty of each task—based on the degree of resource mobilization required by the task. Relatively simple tasks such as the signal-detection tasks described above may be relatively resistant to the negative effects of resource sharing. In this instance, it may be the case that there are ample resources to share between tasks. This seems to also be confirmed by the finding that well-learned or automatic tasks can be maintained more easily than less-well-learned tasks. On the other hand, more complex tasks, presumably requiring greater resource devotion, may be at greater risk for interference and degradation. Although very little research seems to have been conducted on concurrent task management under psychologically distressing conditions, it can be assumed that such stress would compromise the management of resources further, drawing them away from either or both tasks.

The Effects of Time Pressure on Performance

Time pressure has been found to degrade performance across a variety of cognitive domains. The range of performance domains that have been found to suffer under time pressure include: judgment and decision making (Entin & Serfaty, 1990; Raby & Wickens, 1990; Rothstein & Markowitz, 1982; Sperandio, 1971; Stokes, Kemper, & Marsh, 1992; Walton & McKersie, 1965; Zakay & Wooler, 1984), visual search behavior, vigilance and attentional processes (Streufert & Streufert, 1981; Wickens, Stokes, Barnett, & Hyman, 1991; Wright, 1974), memory recall strategies (Cambell & Austin, 2002), concession making and integrative agreements (Pruitt, 1981; Pruitt & Carnevale, 1982; Rubin & Brown, 1975; Walton & McKersie, 1965), and subject's self-ratings of performance (Greenwood-Ericksen & Ganey, 2002). In addition to a general drop in performance, time pressure and the corresponding sense of urgency experienced tends to result in strategy-shifting in teams (explicit to implicit rules and greater coordination between members), task- or load-shedding (of which strategy-shifting may be seen as one specific example), tunneling of attention and visual scanning, and a speed/accuracy trade-off in performance.

Some have argued that time pressure is the central factor at the heart of all performance decrements and that any element that impinges on an operators' workload, does so through this variable. Hendy, Farrell, and East's (2001) information processing model of operator stress is defined by time pressure. These authors posit that time pressure is the underlying stressor that determines operator performance, error production, and judgments of workload. In fact, according to Hendy et al. all factors affecting workload are reduced to this variable. Moreover, the authors suggest that the relationship between a given task load and its corresponding time pressure can be estimated by dividing the task load by the rate at which information (related to the load) can be processed. This equation results in a determination of the decision time needed to manage the load. This figure is further divisible by the time available to the operator to complete the operations in question, which leaves a numerical function representing time pressure. The authors propose three possibilities by which human information processing can reduce load mismatch. The first is reduction in task load or the amount of information required to be processed. The second is an increase in the time available to complete the task, and the third is an increase in channel capacity (regulating the rate and volume of information processing). Hendy et al. are certainly not alone in their alignment of time pressure and workload.

O'Donnell and Eggemeier (1986) also drew a direct connection between these two variables. These authors have suggested that time pressure and workload are the operant conditions that lead to load-shedding. The previous discussion of shedding strategies seems to further support this perspective (Raby & Wickens, 1990; Rothstein & Markowitz, 1982; Sperandio, 1971). Wright (1974) found that time pressure contributed to a state of information overload whereby subjects simply did not have enough time to process information and were forced to simplify their decision task by reducing their visual scans and by considering fewer decision-related alternatives. Entin and Serfaty (1990) placed subjects under the dual workload conditions of time pressure and a secondary task. The authors found that with difficult decision tasks subjects preferred seeking additional input from the easy-to-process opinion of a consultant versus raw data from a sensor probe. This was particularly the case as time pressure and workload increased. This pattern of performance further reflects the common use of resource economizing or shedding strategies through the employment of pre-processed information. To what extent these "strategy-shifts" are motivated purely by anxiety and to what degree they reflect the physical limitation of time is unclear.

Lehner, Seyed-Solorforough, O'Connor, Sak, and Mullin (1997) also examined decision making performance under time pressure. They found that teams used less-effective decision strategies as time pressure increased. Specifically, they used strategies that were more familiar to them versus those that were better but more recently learned. This finding links what is known about our reliance on previous learning under stress and our preferential use of well-learned strategies regardless of their effectiveness. These tendencies may be seen as adaptive in some instances as research has shown that well-learned and proceduralized knowledge sets tend to be resistant to the negative effects of workload and stress.

Using a gambling paradigm, Ben Zur and Breznitz (1981) found that subjects tended to make lower risk choices and spend more time viewing negative dimensions while under time pressure. This tendency to accentuate negative evidence present in their decision making task was also found by Wright (1974). Greenwood-Ericksen and Ganey (2002) explored the effect of time pressure on subjects' ratings of their own performance. The authors found a tendency for individuals to rate themselves worse under time pressure than those not under this pressure (even when there was no difference in objective performance). Thus, not only does time pressure seem to draw some individuals toward an active processing of their negative circumstances; it may also cause them to view their abilities to manage these circumstances in negative ways.

Finally, several investigators have concluded that time pressure increases the level of cooperation between groups in negotiation because it facilitates concession making; however, it has been noted that this may also interfere with the development of integrative agreements due to forced cooperation (Pruitt, 1981; Pruitt & Carnevale, 1982; Rubin & Brown, 1975; Walton & McKersie, 1965).

Driskell, Mullen, Johnson, Hughes, and Batchelor's (1992) meta-analysis of the effects of time pressure on performance revealed that time pressure has a negative effect on performance speed (across various cognitive domains) and accuracy (although the size of the effect is much larger for speed than accuracy). These authors also determined that the effect of time pressure is mediated by the type of manipulation employed. For example, continuous manipulations (shortening the length of the time available for the task) produced strong negative effects for both speed and accuracy, whereas categorical manipulations (stating that subjects should work as fast as possible from the beginning) created mild to moderate increases in speed and actually enhanced performance accuracy slightly. Logically, the magnitude under which an individual is pressured for time affects their performance: the stronger the magnitude, the greater the speed but the more impaired the accuracy for continuous manipulations. The authors found no effect of magnitude on categorical manipulations. Driskell et al. noted that urging an individual when pressured for time also affected their performance. For continuous manipulations, there were strong negative effects for both accuracy and speed of performance when urged.

The authors concluded that the effect of time pressure on performance appeared to be a function of the task. Pattern recognition tasks, vigilance tasks, and reaction tasks were the most negatively effected in terms of performance accuracy while pattern recognition, reaction tasks, and to a lesser degree cognitive tasks, were the most positively effected in terms of performance speed.

The Effects of Thermal Stress (Heat and Cold) on Performance

Under thermal stress (heat and cold) various cognitive processes appear to be impaired and this impairment seems to be related to the severity of these stressors. Cognitive impairments appear to be more prevalent under conditions of cold than those of heat. Most of the research literature in this area has assessed psychomotor and/or perceptual-motor tasks and to a much lesser extent complex cognitive tasks. Accordingly, impairment patterns have been clearly demonstrated among psychomotor skills (particularly fine motor skills under cold conditions), but there are mixed results when it comes to higher-order cognitive abilities.

The explanation for such decrements remains unclear but likely originates from several sources. From a biological or neural functioning perspective, thermal stress may lead to a breakdown in thermal regulation. On the other hand, the discomfort caused by thermal extremes may result in an information processing distraction that interferes with task-related performance (i.e., drawing resources and attention away from the task and toward the subjective experience). Similarly, volitional changes in strategy may occur. For example, it has been suggested that the strategic allocation of resources across different task components may change. In such a case, the shift in resource allocation may accompany a goal shift toward emotion-focused coping—a result of concurrent management of the task demands and the subjective discomfort of the stressor.

The number of contexts in which thermal stressors have been shown to degrade performance is large and includes those in attentive processes (Callaway & Dembo, 1958; Pepler, 1958; Vasmatzidis, Schlegel, & Hancock, 2002), memory (Giesbrecht, Arnett, Vela, & Bristow, 1993; Hocking, Silberstein, Lau, Stough, & Roberts, 2001), psychomotor and/or perceptual-motor tasks (Baddeley & Fleming, 1967; Enander, 1989; Gaydos & Dusek, 1958; Hyde, Thomas, Schrot, & Taylor, 1997; Idzikowski & Baddeley, 1983), problem solving (Fine, Cohen, & Crist, 1960), and under various training environments (Keinan, Friedland, & Sarig-Naor, 1990).

Attentional processing has typically been examined using vigilance tasks. Pepler (1958) found that, under the stress of heat, vigilance decreased over time. Vasmatzidis, Schlegel, and Hancock (2002) found similar decrements in vigilance, visual tracking, and auditory discrimination tasks when participants were subjected to heat. Callaway and Dembo's (1958) examination of cold demonstrated its effects on the judgment of sizes. Subjects were instructed to put their foot into a bucket of ice water simulating stressful conditions related to thermal discomfort. The authors found that the subjects tended to judge the objects as larger than matched controls. Due to the fact that size judgments typically require the incorporation of peripheral cues such as elements in the foreground (shadow, texture, relative position of other objects, etc.), the authors concluded that subjects had not attended to these cues, focusing instead on the central object. These judgments did not appear to be related to ophthalmic changes and Callaway and Dembo (1958) surmised that some physiological mechanism seemed to increase the selectivity of an individual's attention under the stress of cold.

Thermal stressors have also been employed in the study of working memory performance. These examinations have included both heat (Hocking, Silberstein, Lau, Stough, & Roberts, 2001) and cold (Giesbrecht, Arnett, Vela, & Bristow, 1993). Giesbrecht, Arnett, Vela, and Bristow (1993) found that after immersion in cold water, tasks requiring minimal cognitive demands remained unaffected (auditory attention, Benton visual recognition, digit span forward); however, those tasks deemed more cognitively challenging (digit span backward—requiring working memory, and the Stroop task) showed significantly degraded performance. Slaven and Windle (1999) simulated conditions of a disabled submarine and found that under the stress of cold, there were no significant performance decrements (including measures of working memory). However, self-report measures suggested that decrements were perceived. These authors concluded that motivation and the presence of peers (shipmates) may have played a role in mitigating the effects of thermal stress.

Fine, Cohen, and Crist (1960) are one of the few to have studied problem-solving abilities under thermal stressors. They found that there was no difference in performance between 70 degrees and 95 degrees (Fahrenheit) on anagram tasks. Giovani and Rim (1962) failed to find performance decrements in subjects responding to a dominoes task when under heat and they found no difference in performance between heat extremes (77 and 109 degrees). Grether (1973) examined finger tapping, response time, and vigilance behavior. His investigation demonstrated that heat tended to improve performance up until a point after which performance decreased. His results suggested that decrements in this curvilinear relationship occurred reliably after temperatures rose past 85 degrees. Hancock and Vasmatzidis (1998) also found support for a derivation of the Yerkes-Dodson inverted-U performance curve in their review of the literature on heat and performance studies.

Performance on perceptual-motor tasks is perhaps the largest domain in which thermal stressors have been examined. Early investigations by Baddeley and his colleagues tended to lump the stress effects of cold with other anxieties in their evaluation of under-water diving performance (Baddeley, 1966; Baddeley & Fleming, 1967). Enander (1989) examined the thermal stresses of heat and cold on a test of manual dexterity and strength. Although he acknowledged the presence of some direct physiological effects, "the temperature of the hands…is clearly a limiting factor in the performance of manual tasks in the cold", he stated, "…performance on more complex cognitive tasks is the result of an integration of physiological reactions, physical and mental capabilities, and subjective assessments." (p. 28). In his review of the research on the effects of cold, Enander reported that reductions in core body and muscle temperature result in decreases in strength and endurance (Bergh, 1980; Ramsey, 1983) as well as tactile sensitivity at 8-10 degrees Celcius and manual dexterity at 12-15 degrees Celcius (Clark, 1961; Dusek, 1957). Fine motor movements and the manipulation of small objects have also been shown to be impaired when exposed to cold temperatures (Kiess & Lockhart, 1970; Vaughan, Higgins, & Funkhouser, 1968). Enander asserted that research has implicated the role of cognitive distraction in these effects at both cool (15.5 degrees Celcius) and cold (4.5 degrees Celcius) water temperatures (Vaughan, 1977). Exposure to cold air has also resulted in an increase in errors on serial choice-reaction time tasks of varying complexities (Ellis, 1982; Ellis, Wilcock, & Zaman, 1985). Moreover, working memory and encoding processes (likely mediated through attention) have been shown to be impaired when exposed to significant cold (core body temperature of 36.7 degrees) while long-term memory stores remain fairly resistant to such effects (Coleshaw, Van Someren, Wolff, Davis, & Keatinge, 1983).

Enander (1989) also reviewed the research on the effects of heat and found, "there is little initial effect on physical strength, but the gradual accumulation of heat in the body during longer and more intense exposures gradually builds up fatigue and a corresponding decrease in endurance" (p. 29). Vigilance and sustained attention tasks have been the most common types of tasks tested under heat exposure. The overall pattern of effects for heat is somewhat confusing and appears to depend on the task examined and the intensity of the heat experienced. Moreover, when the temperature remains constant (albeit hot), performance decrements are much less (except for extreme temperatures) than when temperature is variable or climbing.

These differential effects have also been noted by others. Driskell, Mullen, Johnson, Hughes, and Batchelor's (1992) meta-analysis of the effects of thermal stress on performance indicate that heat does not significantly affect the speed of performance but does slightly degrade the accuracy of performance. However, these authors found cold temperature significantly affects both the speed of performance as well as the accuracy of performance (moderate effect sizes were found for both outcomes). Driskell et al. also noted that group size was a significant moderator of performance. While there was no effect of group size under heat conditions, there were significant differences in performance under cold conditions—the larger the group, the less was the negative effect of the cold on performance. This finding resembles the "misery loves company" theory reported earlier and may reflect the role that motivation and effort play in reducing the negative effect of thermal discomfort.

Ramsey (1983) postulated that the most significant effect of cold temperature on performance is the loss of manual dexterity of the hands. Gaydos and Dusek (1958) examined the effects of cold on manual dexterity and found that significant impairment occurred when hand skin temperature was below 53 degrees (Fahrenheit). Horvath and Freedman (1957) also investigated the effects of cold temperature on manual tasks (writing ability). These authors observed men working at temperatures of 22 degrees for two weeks noting that significant decrements in manual tasks and writing ability occurred but that general mental and cognitive performance remained intact. Although conspicuously absent from the research literature, the need for a differentiation between direct and indirect effects is no where more necessary than it is here. Presumably, the effects of cold on fine motor control are largely a function of physiology and thermodynamics; however, research on human performance under thermal stress fails to address this issue adequately.

Hyde, Thomas, Schrot, and Taylor (1997) studied the performance of naval special operations forces under real-world stressors. The specific domains in their investigation were predominantly perceptual-motor in nature and included: grip and arm strength, visual acuity, hand-eye coordination, physical endurance, and both fine and gross motor skills. Hyde et al. (1997) examined these performance measures under several adverse conditions to include winter-warfare training and underwater diving operations. There was a general pattern of performance decrement that emerged. The exposure to cold, associated with the winter-warfare training, reduced fine motor skills and hand strength. While reducing manual dexterity over time, exposure to cold and the elements in underwater diving impacted fine motor skills but not large muscle group performance. These findings are consistent with previous investigations (Idzikowski & Baddeley, 1983). Overall, fine motor skills were more susceptible to disruption and degradation than gross motor skills.

Several researchers have investigated the role of motivation and effort in staving off the effects of thermal stress. As mentioned above, Slaven and Windle (1999) found few if any significant performance decrements using a disabled submarine simulation. They surmised that motivation may have played a role in mitigating the effects of thermal stress. Razmjou and Kjellberg (1992) explored the effects of heat on a serial-choice reaction task. They found that heat increased the frequency of errors but did not impact reaction time. The authors asserted that this finding was possibly offset by the allocation of additional effort (based on the self-report of their subjects). Razmjou (1996) subsequently provided a framework for the analysis of stress states. He examined two control processes, strategy and effort. Razmjou found that providing feedback to subjects regarding their performance resulted in improvements under the stress of heat. These findings taken together seem to suggest that appraisal, goal structure, and subsequent effort can, and often does, moderate the negative effects of some thermal stress conditions.

The Effects of Noise on Performance

In general, exposure to noise tends to degrade performance. Although the results are mixed, most studies find that intermittent noise is more disruptive to performance than continuous noise. However, definitive conclusions about decibel level at which performance decrements are shown are difficult to draw since the research findings in this area have also been mixed. As the nature of the task changes, the effects change. For example, psychomotor tasks appear to be less affected by noise than higher-order cognitive processes. As one might expect, this is likely to be related to the findings previously reported concerning the resilience of proceduralized or implicit skills and knowledge. Undoubtedly there is a shared mechanism which facilitates these performance patterns.

The research on the effects of noise on performance is relatively well-developed. This maturity owes much to a handful of dedicated individuals who have investigated this area extensively and includes the work of Donald Broadbent, Robert Hockey, and Christopher Poulton. The examination of the effects of noise on performance has occurred across several domains to include vigilance and attentional tasks (Broadbent, 1954; Broadbent & Gregory, 1963; Broadbent & Gregory, 1965; Broadbent, 1971; Hockey, 1970), memory (Poulton, 1978; 1979), reaction-time (Allen, Magdaleno, & Jex, 1975), psychomotor tasks (Cohen & Weinstein, 1981; Theologus, Wheaton, & Fleishman, 1974), and the ability to distinguish social roles (Rotton, Olszewski, Charleton, & Soler, 1978).

Broadbent was one of the first to systematically examine the relationship between noise and tasks of vigilance (1951). Across a series of investigations, he and his colleagues demonstrated significant impairment in sustained attention at the level of 100 dB of noise (Broadbent, 1954; Broadbent & Gregory, 1963; Broadbent & Gregory, 1965; Broadbent, 1971). Hockey (1969) reviewed the effects of noise on performance and found a wide range, from impairment to improvement. These mixed results led the author to examine the effects of noise on attention. His review suggested that the effects of noise were mediated by attentional selectivity (Easterbrook's hypothesis) and Hockey decided to test this theory further (Hockey, 1970). He employed a dual-task of pursuit-tracking and multi-source monitoring under two noise level conditions (70 dB and 100 dB). Subjects were tasked with manually aligning a pointer with a moving target while visually scanning a series of light flashes and responding with key strokes accordingly. Hockey's (1970) results support the notion that noise has differential effects on performance. Performance on the designated primary task (manual-tracking) was enhanced through the application of loud noise (relative to quiet). Performance on the secondary task (light detection) was enhanced in central-feature performance but not in monitoring lights on the periphery. Hockey concluded that these findings support the presence of a noise-induced attentional-selectivity mechanism.

Hockey has provided several subsequent reviews of this literature (Hockey, 1978; Hockey, 1979; Hockey, 1983). He suggested that two theories account for the effects of noise on performance. The first is distraction theory. This theory is largely based on Broadbent's (1958) earlier model of information processing and simply states that noise interferes with performance. Specifically, it posits that a human's information processing center is singular and of limited capacity. Often referred to as Broadbent's filter theory, the model proposes that information is filtered and either selected for further processing or discarded. Moreover, Broadbent argued that, at some point along the way, information coming in for processing must be reduced to a single channel of limited bandwidth. Thus was born the bottleneck theory of information processing that has been discussed previously. The second theory maintains that noise facilitates functioning by stimulating processing. This perspective, based on arousal theory, is deeply rooted in the position that central nervous system activation is required for information processing and that such activation initiates and sustains processing. Applied to noise, the theory suggests that such stimulation increases arousal, facilitating a concomitant increase in performance up to a point where over-arousal occurs, resulting in corresponding decrements in performance.

Hockey’s (1979) review of the literature provided nine conclusions regarding the effects of noise on performance: 1) noise results in both positive and negative outcomes; however, these are less likely to occur early in performance, 2) negative effects have a greater likelihood among complex tasks, 3) improvement from noise exposure is often seen in less complex tasks or those in which boredom is experienced (noise acts to increase alertness), 4) low to moderate levels of steady noise (<90 dB) are not as likely to effect performance as intermittent noise or noise above these levels, 5) memory effects can occur with as low as 70-80 dB of noise early on in task performance, 6) verbal comprehension can be negatively affected by noise that is less than that needed to impair the intelligibility of speech, 7) noise can increase attentive focus during the encoding of information while reducing the availability of that information, 8) noise’s central effect on information processing is to tunnel attention toward the central-features of a task, and finally, 9) noise appears to increase one’s subjective sense of confidence in one’s decision making even though no additional evidence for such confidence has been added.

One of the most frequently reported decrements in the literature is the masking of speech. Obviously, if the interference of the noise is so great that one can not hear, any hope of processing the information is all but lost. Hockey points out that the risk for such problems in human communication is greatest when encountering sounds in the lower register as most of human speech occurs among the lower sound frequencies. Hockey wasn’t the only one to explore the relationship between acoustic masking and performance. Poulton (1978) asserted the notion that the introduction of noise resulted in the masking of acoustic cues and a reduction in subvocalizations so that individuals couldn't “hear themselves think.” This loss in subvocalization has been construed as a loss in attention to internal thoughts and ideas. Thus, without the ability to monitor and engage in internal dialogue, performance on various tasks is likely to be degraded. In a further description of this process, Poulton (1979) suggested, “…performance may improve initially because of an increase in arousal. If performance is disrupted by the masking of audible feedback or inner speech, the initial improvement in continuous noise may become a decrement, as arousal falls and no longer compensates for the masking.” (p. 361).

Accordingly, noise can either improve or degrade performance. Improvements in performance typically occur soon after the noise is initiated while decrements typically arise later and may continue (an aftereffect) after the noise has ended. In appreciation of both the distraction and arousal theories, Poulton provided descriptive evidence of both. He reported that when noise creates masking of acoustic feedback or inner speech, performance decrements are immediate, as soon as noise begins, and should return to normal once noise discontinues. However, noise also produces arousal which typically improves performance initially; however, as noise continues and adaptation occurs, performance will drop along with the corresponding reduction in arousal. Poulton observed that when noise is discontinued, arousal often drops below baseline, resulting in a brief decrement in performance until such levels return to normal. Poulton further provided us with an explanation behind the effects of noise on memory. He stated, “Continuous noise interferes with the storage of words probably by reducing the duration of the storage. More frequent rehearsal is therefore required to maintain the words in working memory. The more frequent rehearsal occupies the limited-capacity processor more of the time, leaving less time available for additional processing.” (p. 364). This latter finding was corroborated by the work of Carter and Beh (1989) who reported finding that an individual’s cardiovascular responses to acute noise habituated quickly unless the individual was involved in a high-demand or complex task. Poulton’s investigations found reliable decrements in performance under continuous noise conditions occurring after exposure to 75-80 dB.

In response to Poulton's statements, Broadbent (1978) argued convincingly that the effects of noise were not simply due to acoustic masking. Instead, he cited numerous empirical findings that support two alternative hypotheses. The first hypothesis is that noise alters the salience in items to-be-remembered from memory, favoring what he referred to as "dominant items." Drawing on the wake of findings that followed Easterbrook's tunnel hypothesis, Broadbent proposed that the mechanism by which this occurs is attentional selectivity. Thus, as a result of differential attentive processing, the saliency of items must change, which leads to their prominence in later recall from memory. His second hypothesis suggests that Baddeley's (1976) articulatory loop is highly active in the memorization of items under noise conditions. As a result he suggested, "Not masking of internal speech but talking to oneself at all costs offers a more plausible explanation of the results." (p. 1062).

Several specific assertions have received attention in the noise-performance literature. For example, it has been suggested that intermittent noise generally seems to evoke a greater negative reaction to performance than continuous noise (Coates & Alluisi, 1975; Eschenbrenner, 1971; Glass & Singer, 1972; Theologus, Wheaton, & Fleishman, 1974). This has been found to be the case when the noise is random or aperiodic as well, and, in fact, it has been suggested that such noise produces greater performance decrements (Percival & Loeb, 1980).

Various investigations have come to the conclusion that lower-order cognitive tasks such as perceptual-motor tasks are fairly resistant to the effects of noise (Cohen & Weinstein, 1981; Harris, 1973; Theologus, Wheaton, & Fleishman, 1974) while higher-order cognitive tasks tend to be relatively sensitive to both the disruption and enhancement of noise (Loewen & Suedfeld, 1992; McCormick & Sanders, 1982). Hartley (1981) studied the effects of noise on a motor-pursuit tracking task. He found decrements in performance when subjects were exposed to 95 dB of noise. Stokes, Belger, and Zhang (1990) also found that noise made performance on psychomotor tasks worse. However, they noted that the effects of this stressor on the Stroop task resulted in an increase in the speed of responses which enhanced performance (possibly facilitated by a tunneling of attention). Schmidgall (2001) reported that the stressors of noise and other environmental factors tended to degrade performance on psychomotor and attention (vigilance/scanning) tasks primarily when the tasks were complex.

Several authors have explored noise-induced startle and its affect on performance. Sternbach (1960) and May and Rice (1971) both found slowed reaction times and general physiological activation in subjects after exposing them to an unexpected pistol shot. Thackray (1965) extended this study by the use of unexpected loud noise (120 db) followed by intervals of moderate to loud noise. Subjects were asked to perform a variety of flight-related tasks during their exposure to the unexpected and unpredictable noises. Thackray found a strong physiological reaction related to the onset of the noise conditions as well as a disruption in subject's initial reaction to the task. However, subjects appeared to improve their performance on these tasks as subsequent noise was experienced. Across a series of studies, the authors found that subjects tended to recover from their initial autonomic reactions to the startling events. This recovery was also associated with an improvement in performance following their initial responses. The authors concluded that performance disruption following startle typically lasts between one and three seconds (although some residual effects can be present up to 10–20 seconds after the event). This disruption was generally found to be directly related to increases in autonomic activation.

Although there are differences in the findings of many investigations, most research on dB level seems to indicate that impairment in performance can be reliably observed (depending on the task) after exposure to between 90 and 100 dB of noise (Broadbent, 1954; Broadbent & Gregory, 1963; Broadbent & Gregory, 1965; Fornwalt, 1965) although cognitive impairments have been recorded under as low as 68 dB of noise (Weinstein, 1974). Most of these investigations have examined performance on tasks of sustained attention.

Driskell et al.'s (1992) meta-analysis into the effects of noise on performance suggests noise has a negative effect on the accuracy of performance but that it does not generally have such an effect on the speed of performance. The size of this effect is reportedly mild to moderate. Driskell et al. also found that noise has a negative effect on the perceived stress level of individuals exposed to it (a strong effect size reported). These authors point out the various moderating factors involved in studying the effects of noise on performance. These factors include the intensity of the noise studied, whether it is intermittent or continuous, its duration, mode of delivery, and of course the type of task being assessed. For example, although commonly reported in the literature, these authors found no significant difference in effect between continuous and intermittent noise (across measures of distress, accuracy or speed). There was a trend found that suggested that under continuous-noise conditions individuals tend to perform more slowly while the opposite is the case under conditions of intermittent noise. It should also be noted that individuals tend to habituate to continuous noise over time, resulting in gradually improved performance. This does not appear to be the case under intermittent noise conditions.

They did note that there was greater self-reported distress as noise decibel level increased. Moreover, the accuracy of performance was also degraded somewhat as a function of increased noise intensity; however, performance speed appeared to be unrelated to decibel level. There was no consistent relationship between the duration of noise and the performance decrement observed. Impairment in performance speed was noted when individuals were exposed to intermittent bursts of noise over time but not continuous noise. Individuals also tended to report experiencing less stress as noise endured even though their performance did not improve. This too seems to suggest that as the duration of noise increases, individuals habituate to the noise. The authors theorized that this may result in the blocking of some environmental inputs in certain circumstances, which in turn may result in the filtering-out of some task-relevant information (leading to performance degradation).

Driskell et al. (1992) found small to moderate negative noise effects concerning performance accuracy on various cognitive, psychomotor, and working memory tasks. On the other hand, small to moderate positive effects were found on tasks of pattern recognition. The effect of noise on the speeded performance of these measures was negligible. The authors provided a graded effect-rating based on the level of noise intensity. The results of their analyses suggest that mild distress typically does not occur until reaching over 80 dB of noise. Moderate distress tends to be reported when noise levels exceed 85 dB and not until noise is greater than 91 dB do individuals tend to report a large negative effect. In terms of objective performance, noise levels as small as 76 dB appear to be related to decreases in accuracy; however, to witness moderate-sized effects in most performance domains, noise intensity must reach around 145 dB.

The Effects of Fatigue on Performance

Although it will come as no surprise, the research on fatigue and performance consistently indicates that fatigue tends to degrade performance. Furthermore, the negative effects of fatigue increase as sleep is deprived for greater periods of time. Are these effects due to stress or the direct role fatigue plays? The answer is unclear. This review has included fatigue as a putative stressor in light of the convention for doing so in the stress and performance literature; however, few, if any, studies have definitively separated direct from indirect effects concerning fatigue.

Before a further discussion of these effects, a brief review of the construct of fatigue is necessary. Job and Dalziel (2001) reviewed the concept and concluded that researchers have long struggled with how to define and study fatigue. A quick review of previous investigations bares this out. For example, there are numerous operational definitions of fatigue and little consensus on how to bind the construct. Brown (1994) suggested that, "psychological fatigue is defined as a subjectively experienced disinclination to continue the task" (p. 298). Cercarelli and Ryan (1996) indicated that, "fatigue involves a diminished capacity for work and possibly decrements in attention, perception, decision making, and skill performance." Perhaps most simply put, "fatigue may refer to feeling tired, sleepy, or exhausted." (NASA, 1996). Job and Dalziel (2001) posted the following definition of fatigue:

> a state of an organism's muscles, viscera, or central nervous system, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or system wide energy to maintain the original level of activity and/or processing by using normal resources. (p. 469).

Gawron, French, and Funke (2001) provide an overview discussion of fatigue, and these authors suggest that there are two types. They consider physical fatigue peripheral, "…a reduction in capacity to perform physical work as a function of preceding physical effort." On the other hand, mental fatigue they contend is central, "…inferred from decrements in performance on tasks requiring alertness and the manipulation and retrieval of information stored in memory." (p. 581). Desmond and Hancock (2001) also identified two different types of fatigue but chose to classify them as passive and active. These authors suggested that passive fatigue is that which resembles vigilance—resulting from passive monitoring of a given system with little if any active interaction with that system. As one might guess, active fatigue has been defined as that which results from the continuous or prolonged interaction with a system. Desmond and Hancock defined fatigue as, "a transition state between alertness and somnolence." (p. 459).

Matthews and Desmond (2002) have observed that fatigue is typically thought of in relation to energetical concepts (i.e., effort, resources, activation). In an attempt to explain the effects of fatigue on performance, these authors noted that research points to three competing hypotheses. One hypothesis proposes that fatigue removes resources in some direct way or perhaps indirectly diverts them toward coping strategies. Thus, performance falls off on tasks due to the depletion of resources. This is consistent with the notion that more complex tasks are more sensitive to fatigue effects since these types of tasks are also likely to require greater resources to maintain. However, a second hypothesis suggests that fatigue is related to effort regulation. Several investigations have shown that individuals under fatigue states generate less effort than those not fatigued (Fairclough & Graham, 1999). There is some indication that fatigue is a state of under-arousal which fails to actively mobilize the resources or effort required to achieve or sustain strong performance. This second situation reflects less of a resource insufficiency and more of an activation insufficiency. Finally, it has been suggested that a combination of these two hypotheses best explains fatigue's effects and the underlying mechanisms at work.

Confusion and disagreement over what defines fatigue has also led to difficulties in measuring fatigue. Several researchers have equated this difficulty to the one experienced with the concept of stress in general (Tepas & Price, 2001). Muscio's (1921) quandary was mentioned earlier and applies equally well to fatigue. If we are to define any phenomenon, we first need to be able to measure it. However, it is difficult to create such a measure without knowing what you are trying to measure. This circular reasoning has left many to wonder, what is the most appropriate way to measure fatigue? Job and Dalziel (2001) have commented that this issue has complicated the development and assessment of fatigue countermeasures. In many instances, fatigue is spoken of as being present or absent, yet theoretically most consider it to be a continuous variable. Thus, at what degree of subjective experience or objective measure is one to be considered fatigued? Although many questions remain, the research literature on fatigue and the best ways to measure the construct have begun to converge (M. Mallis, personal communication, November 2003).

In various reviews of the fatigue literature, visual scan and attentional processes have been shown to be particularly sensitive to disruption (Ainsworth & Bishop, 1971; Banks, Sternberg, Farrell, Debrow, & Dalhamer, 1970; Drucker, Cannon, & Ware, 1969). These investigations have typically employed between 36 and 48 hours of sustained performance to achieve the states of fatigue studied. However, it should be noted that as little as 20 minutes of certain tasks have been used to induce fatigue. Haslam and Abraham (1987) examined performance on a continuous task for 90 hours. Their results indicate that fitness remains relatively unaffected while mood and mental ability decline significantly under a fatigued state. Cognitive measures suggested that vigilance and complex cognitive performance were most sensitive while simple, well-learned tasks suffered least. This finding was confirmed by Soetens, Hueting, and Wauters (1992) who noted that fatigued individuals did worse on complex decision tasks but not on more simplistic tasks. These findings are consistent with the general notion that well-learned or proceduralized tasks are relatively resistant to stress effects.

Fatigue states have also been studied under a number of contexts. In each case, sleep deprivation is typically paired with sustained performance on a given task (i.e., vigilance). Across this broad range of settings, fatigue has been shown to diminish performance. For example, Bartlett (1953), in an examination of aircrew (monitoring aircraft instruments) under fatigue, found that increasingly larger deviations of instrument readings took place, as well as increased levels of distraction, cue restriction (focusing in on the central task and neglecting peripheral cues), and response variability, as the aircrew's state of fatigue was prolonged.

Buck-Gengler and Healy (2001) studied fatigue on a data-entry task (typing) and found that response time was enhanced as mastery on the task was developed; however, accuracy diminished as fatigue set in. Matthews and his colleagues have studied driving stress and fatigue extensively (Matthews & Desmond, 2002). Examinations of driving behavior under the strain of fatigue have revealed general deficits in lane deviations and difficulty maintaining lateral positioning (Brookhuis & De Waard, 1993; Brookhuis & De Waard, 2001). Matthews and Desmond (2002) designed two experiments under simulated driving conditions to assess subjective and performance-based measures of fatigue. Fatigue was induced in drivers through the implementation of a high-workload pedestrian detection task while driving. This condition was maintained for approximately 24 minutes followed by a drop in the dual-task demands (subjects continued to drive but not detect). Objective measures of performance included lateral tracking and steering reversals. Subjective measures were assessed using the Task-Induced Fatigue Scale (fatigue), the Dundee State Questionnaire (emotion and motivation), and the NASA-TLX (workload). The results of this investigation revealed that motivation toward task achievement and active coping decreased as the fatigue-induced condition persisted. Fatigue subsequently increased heading errors, reduced steering activity, and reduced perceptual sensitivity.

In order to replicate these findings and further test their motivational hypothesis, Matthews and Desmond (2002) constructed a second experiment. Conditions were identical with the exception of a motivational message encouraging participants to "make a special effort to concentrate" during their performance. They were told that their driving skill was being measured. The results of this second experiment were consistent with the earlier findings. They suggest that fatigue effects are moderated by motivation which further supports the effort-regulation hypothesis over the resource-depletion model—when demands are low individuals experience greater difficulty in mobilizing sufficient effort to perform as well. The authors contend, “Interventions should be geared towards enhancing driving motivation, rather than reducing attentional demands on the driver.” (p. 681).

Haslam (1978) explored the effects of sleep deprivation on a group of military parachute troops. He deprived these individuals of sleep for nine days while they conducted routine training operations. Following the third night without sleep, the platoon was considered ineffective (rated by the platoon’s leaders). However, after being given three hours of sleep a night, performance effectiveness remained adequate for all nine nights evaluated. This and similar findings have led many researchers to examine the level of sleep deprivation that individuals can incur while still sustaining adequate performance. In this same vein, Rosenberg and Caine (2001) surveyed military pilots concerning fatigue in regular operations. Their survey data show that military pilots feel they should be required to arrive earlier for night flights (to facilitate napping), that the squadrons should improve their flight scheduling, that they should be allowed to use stimulants to sustain their alertness, and that squadrons should routinely brief the issues concerning fatigue and their countermeasures.

Caldwell and his colleagues have examined the use of various fatigue countermeasures in sustained flying operations in the military (Caldwell, 1997; Caldwell & Caldwell, 1997; Caldwell & Gilreath, 2002). Caldwell (1997) determined that pilots were able to improve restfulness and restore their sleep patterns after using a self-administered relaxation therapy. He and others have also shown that various pharmacological interventions (Modafinil/Provigil R and Dextroamphetamine/Dexedrine R) can be incorporated into stress management procedures to improve performance, mood ratings, and physiologic measures of alertness (Caldwell, 2001; Caldwell & Gilreath, 2002). Caldwell and Caldwell (1997) also found that Dexedrine could be employed to improve flight performance across a number of dimensions including: maintenance of heading and airspeed, roll control, turns, slips, and localizer tracking across all phases of flight.

Van Dongen, Maislin, Mullington, and Dinges (2003) explored the degree to which sleep can be reduced prior to inducing cognitive performance deficits. In their experiments subjects were randomly assigned to one of two sleep restriction groups (four hours or six hours) or a control group (eight hours) for 14 days. An additional group was restricted from sleep for three days. Subjects were tested across a variety of cognitive measures (psychomotor, vigilance, and working memory). The results of this investigation revealed an almost linear relationship between the amount of sleep restricted and the degree of cognitive impairment across measures. Both the four and six hour restrictions demonstrated deficits that were dose-dependent (as did the total deprivation group). The authors concluded “restriction of sleep to 6 hours or less per night produced cognitive performance deficits equivalent to up to 2 nights of total sleep deprivation…moderate sleep restriction can seriously impair waking neurobehavioral functions in healthy adults.” (p. 117). Interestingly, the authors reported that subjects tended not to be aware of their cognitive deficits.

Driskell et al.’s (1992) meta-analysis concerning the role of fatigue on performance suggests that fatigue negatively affects self-reported distress ratings, as well as objective measures of performance accuracy and speed. Furthermore, as deprivation of sleep increases (increasing fatigue) individuals tend to continue to perform poorly, but rebound slightly over time (perhaps coping or acclimatizing to their fatigue). As the duration of the task while fatigued increases there tends to be a small decrease in performance speed and a moderate decrease in accuracy (across a wide domain of cognitive tasks).

Driskell et al. also found that when tasks are self-paced, there is less negative effect on the speed of one's performance but found this is not the case when tasks are work-paced. The author's meta-analysis also showed that the larger the group, the worse the speed of performance. However, when examining self-reported distress and performance accuracy, the larger the group, the better the performance. This second finding regarding group size appears to support the "misery loves company" hypothesis presented previously, but only in terms of subjective ratings. Finally, based on established circadian patterns of performance the authors mapped diurnal rhythms with sleep-deprivation effect patterns. The results of this suggest that fatigue has its greatest negative effect when the rhythm is lowest (2-8 AM) and is least disruptive when the rhythm is highest (6-10 PM).

Moderator Factors and the Effects of Stress on Performance

There are a handful of factors that appear to play a moderating role in stress's effects on performance and information processing. Although their relationship to these processes is poorly understood, these factors are generally thought to be related to motivation, goal structure, and arousal or activation levels.

The Presence of Others

Under stress, the presence of others appears to affect performance in both positive and negative ways. These two outcomes have generally been termed "social facilitation" and "social impairment," respectively. While the field of social psychology has provided a large literature supporting these findings, only the handful of studies appearing in the cognitive psychology and human performance domain have been included in this review.

Performance seems to be facilitated on simple or well-learned tasks when others are present. One suggestion for this finding is that such tasks are believed to occur under automatic processes. On the other hand, performance tends to be degraded on complex, poorly-learned or novel tasks when an audience is present. These latter tasks are believed to require controlled processing which may account for their vulnerability. These findings appear related to the assertions of Beilock and Carr (2001) and others (Allport, Antonis, & Reynolds, 1972; Beilock, Carr, MacMahon, & Starkes, 2002; Katz & Epstein, 1991) reviewed previously. Carver and Scheier (1981) found this degradation to be particularly likely of complex tasks performed in the presence of others when there was a discrepancy between the individual performer's self-evaluation of their performance and their performance expectations (i.e., when they expected to perform better than they thought they did). Bond (1982) also examined performers' expectations and found that when an individual expects to do well, the presence of an audience helps; however, if the individual expects to do poorly, then the presence of an audience tends to hurt performance. Several subsequent investigations have confirmed these notions (Geen, 1979; Sanna & Shotland, 1990).

It has been suggested that this type of performance outcome may be contingent on the presence of a highly evaluative audience (as compared to a less evaluative audience). An assessment of whether an audience is evaluative is likely to be cognitively mediated. Cottrell (1972) argued against the notion that the mere presence of the audience affects a performer. On the contrary, he conjectured that the audience present must have the potential to evaluate the performer. He argued that this condition was likely to lead to an increase in arousal which would then result in feelings of apprehension and ultimately performance degradation. In accord with this assertion, Paulus and Murdoch (1971) suggested that the more evaluative the audience, the greater the performance impairment was likely to be.

Social Facilitation and Prosocial Behavior

In a related line of research, several investigations have implicated stress in prosocial or social facilitation behaviors. Specifically, it has been postulated that under stress, prosocial or social facilitation behavior (i.e., the likelihood that an individual will help another) decreases. Mathews and Canon (1975) found that individuals were less likely to help others when exposed to loud noise. Similarly, Sherrod and Downs (1974) determined that subjects were less likely to volunteer to perform a requested task when exposed to noise. The reader is directed toward the social psychology research literature for further support of these assertions (Bond & Titus, 1983; Cacioppo, Rourke, Marshall Goodell, & Tassinary, 1990; Cohen, 1980; Zajonc, 1965).

Group Member Status

Under stress, the dynamic of group relationships between high-status group members (i.e., leaders) and low-status group members (i.e., followers) changes. Specifically, an individual's view of their performance as well as their perspective of others' performance may be altered. Westman (1996) found that when raters were in stressful jobs, they evaluated managers who were also in high-stress jobs as less effective than managers in low-stress jobs. In contrast, when these same raters were in low-stress positions, they evaluated managers in high-stress jobs as more effective than managers in low-stress jobs. Thus, how stressed an individual is can affect the judgments they make concerning their manager or leader.

Under stress and workload, lower-status group members are more likely to rely on their leader's decisions and to look to them for making decisions. For example, Helmreich (1979) found that non-lead aircrew tended to defer to their leader's decisions under stress. This has been confirmed by others (Foushee, 1984; Foushee & Helmreich, 1988). Driskell and Salas (1991) also examined the performance of the flight crews under stress and found that under low-stress conditions, low-status group members tended to be more likely to defer to high-status members, while high-status members tended to be more likely to ignore low-status members' inputs. However, under stress, these authors found that while low-status members were still more likely to defer to the high-status members, high-status members under stress were more open to their inputs.

Personality

Personality appears to have some, but probably a limited, role in moderating reactions and performance while under stress. Ackerman and Kanfer (1994) found that individual differences, as measured by the five factor model of personality (NEO PI-R), accounted for some differences in cognitive measures of performance; however, cognitive ability tests accounted for more of the variance. These authors asserted that personality measures offer little incremental validity above and beyond cognitive ability measures. Revelle and Anderson (1999) examined the role of impulsivity and neuroticism measures in performance. They noted a shift in these indices as a result of diurnal arousal rhythms. In particular it was observed that measures of energetic and tense arousal ebbed and flowed in response to these rhythms. Moreover, energetic arousal has been found to be related to an increase in working memory capacity while tense arousal has been shown to reduce this capacity. The authors concluded that impulsivity interacts with time of day to affect the detection and retrieval of information. This interaction subsequently affects performance accordingly.

Several investigations have examined the role of trait and state anxiety in cognitive performance. While much of this literature has already been reviewed under the cognitive appraisal and attentional bias sections, trait anxiety is also related to personality. Wofford, Goodwin, and Daly (1999) have found that low-trait anxious individuals are less prone to the negative effects of temporary stressors in terms of cognitive performance than high-trait anxious individuals. This finding has been well-established across a variety of indices (Wofford, 2001; Wofford & Goodwin, 2002). For a further discussion of this factor the reader is refered to the previous section in this review regarding attentional bias.

Using Fiedler's leadership model Pereira and Jesuino (1987) found that leader behaviors could result in significant improvements in their followers' experience of stress. Similarly, it has been found that airline crew captains with more confidence tend to have crews who report experiencing less stress. This finding may not necessarily suggest that captains who are more confident are more skilled. For example, Bowles, Ursin, and Picano (2000) found that aircrews that were led by captains with greater knowledge and self-confidence reported experiencing less stress, but did not perform differently than crews with less confident and less knowledgeable captains.

Emotional Awareness

Finally, there is some evidence to suggest that individuals with greater awareness of their emotional states—the ability to label their current feelings—perform better under stress than those unable to do so. Worchel and Yohai (1979) found that individuals who were able to label or identify the novel physiologic reactions they experienced under stress were less distressed by them and they performed better. Similarly, Gohm, Baumann, and Shiezak (2001) noted that individuals who are able to label or identify their emotional reactions to stressful events appear to have more attentional resources (perhaps due to engaging in fewer ruminations) to devote to tasks. The result is improved performance compared to those who are not able to label their emotional experience. It seems reasonable to conclude from these findings that cognitive appraisal is at least one explanatory mechanism. Those who can introspect and cognitively frame their experience are likely to feel better and improve their sense of control and predictability over their reactions than those unable to do so. These factors have previously been shown to be of value in reducing the negative effects of stress exposure.

Additional Areas of Discussion

Stress Interventions

When we turn our attention to the research literature on the management of acute stress, several themes emerge. First, it seems clear that most programs designed to deal with stress are based on secondary or tertiary prevention models. That is to say that they target either those deemed to be at risk for acute stress (stress inoculation protocols) or those that are already symptomatic in some way, having been exposed to stressors (stress management programs). While strongly related to one another, each approach has some distinguishing characteristics.

Stress Inoculation Training

Stress inoculation, as the name suggests, attempts to immunize an individual from reacting negatively to stress exposure. This process takes place prior to experiencing the stressful conditions in question. There are at least two implicit assumptions in such a model - both the individual and the condition are identified a priori. For example, experience has taught us that psychologically preparing fire fighters and emergency medical personnel prior to their engagement in stressful events assists them in managing the psychological distress of the event when it actually occurs (Meichenbaum, 1985). While there are several different models for such interventions, most rely upon psychoeducational principles and thought or appraisal restructuring. One critical hallmark of stress inoculation is the requirement for increasingly realistic pre-exposure through training simulation. The model proposes that through successive approximations, one builds a sense of expectancy and outcome that is integrated into positive cognitive appraisal, a greater sense of mastery and confidence. Furthermore, one often habituates to what might otherwise be an anxiety-producing condition. This habituation may in turn diffuse affective states that would otherwise draw upon performance resources and hamper efficient information processing (as discussed previously). This cognitive-behavioral, pre-emptive approach to stress prevention has been implemented in a variety of settings to include work with the military, law enforcement, fire fighters, medical personnel, and many others (Meichenbaum, 1985).

Stress management differs slightly from stress inoculation. The management of stress implies that stress or exposure to stressors has already occurred. Thus, the management of symptoms related to stress reactions is of primary consideration. As one might imagine, this model has primarily evolved from clinical applications. Most stress management programs draw largely on cognitive-behavioral principles. Psychoeducational methods and cognitive restructuring are cornerstones of this approach, as they are in most inoculation protocols. While there are some differences in actual cognitive technique and process between inoculation and management, the greatest difference is typically one of timing and purpose.

Both of these approaches have been reviewed extensively. In general, stress management and stress inoculation programs appear to have a positive effect on subjective measures of stress and anxiety prior to and during performance; in some circumstances this has been related to an improvement in actual performance across a number of real-world domains. For example, early investigations addressed the effect of preparatory information on medical patients pending operations and other stressful procedures (Auerbach, Martelli, & Mercuri, 1986; Egbert, Battit, Welch, & Bartlett, 1964; Langer, Janis, & Wolfer, 1975; Turk, Meichenbaum, & Genest, 1983; Weisman, Worden, & Sobel, 1980). Other applications of the strategy have included work in anger management (Bistline & Frieden, 1984; Egan, 1983; Novaco, 1975) and the control of anxiety (Altmaier, Ross, Leary, & Thornbrough, 1982; Meichenbaum, 1971; Salovey & Harr, 1983), and in work with law enforcement personnel (Novaco, 1977; Novaco, 1980; Sarason, Johnson, Berberich, & Siegel, 1979), and the military (Novaco, Cook, & Sarason, 1983).

Inzana, Driskell, Salas, and Johnston (1996) provided a concise review of stress inoculation research and the assumptions that underlie most models of preparatory information training. They highlighted three phases of preparatory information strategies: sensory, procedural, and instrumental. The sensory training phase consists of information about how one may feel physiologically (general arousal activation) and emotionally (negative affective state activation). The second phase, procedural information, details the environmental events likely to take place during the stressful condition. For example, aircrew facing an emergency descent might be told to prepare for the sounds of warning systems, the visual display of caution and warning lights, time pressures to access and complete emergency checklists and procedures, and frequent communication interruptions concerning clearances and heading changes. Finally, during the instrumental phase of preparation, countermeasures are discussed and recommendations for various intervention or coping strategies are provided.

Inzana and colleagues (1996) offered an explanation for the mechanisms that facilitate these processes and in doing so they suggested that the protective factors related to stress inoculation are many. For instance, they argued that preparatory information reduces the novelty of an emergency or stressful task. This may have several results, not least of which is reducing the tendency to focus narrowly on threat-related stimuli (e.g., weapon focus), thereby diverting mental resources from task-relevant demands. Second, this information may increase the likelihood of a positive expectation and a greater sense of predictability and control. Both of these factors have already been implicated in the reduction of performance via resource diversion. Finally, by reducing unpredictability and novelty and increasing a sense of personal control and self-efficacy, one is more likely to appraise a situation positively and thus reduce both physiological and emotional reactivity. As an illustration of this theory, the authors designed a realistic naval decision making task incorporating vigilance, visual tracking, and pattern recognition. Navy personnel were asked to determine the type of a craft, its status, and intentions under normal and high-stress conditions. Task load, distraction, and time pressure constituted the various stress manipulations in the study. The results demonstrated that preparatory information improved the awareness of the subjects and their ability to respond to the distractions introduced in the task. Further, these individuals reported experiencing less subjective distress, and greater confidence and self-efficacy, and they made fewer errors in the decision making task. In sum, these authors concluded that stress inoculation improved performance across a number of dimensions.

In a similar review, Saunders, Driskell, Johnston, and Salas (1996) conducted a meta-analysis of stress inoculation studies. The authors described three phases of training that are related to, yet distinctly different than those outlined by Inzana et al. (1996). Specifically, Saunders and colleagues posited an educational component, a skill acquisition and practice component, and an application component. Their analysis was directed toward determining the outcome of such training on both subjective (anxiety) and objective (performance) measures. Their results suggested that the overall effect of inoculation programs is strong ($r = .509$) for reduction of performance anxiety (anxiety stemming directly from a task). This effect is moderate ($r = .373$ and $.296$, respectively) in terms of reducing state anxiety (anxiety that is not necessarily task-related) and similar in terms of ultimate performance enhancement. These effect sizes are considerable when you compare them to the effects of other training interventions such as mental practice ($r = .255$; Driskell, Copper, & Moran, 1994) and over-learning ($r = .298$; Driskell, Willis, & Copper, 1992).

These authors determined that the number of training sessions needed to inoculate an individual was relative to the size of the outcome. In terms of reducing performance anxiety, their investigation found that the greater the number of training sessions, the better. They also concluded that there was no difference in effect on performance or state anxiety measures between laboratory or field interventions. Programs that used imagery components were more effective at reducing performance anxiety; however, those that included behavioral practice in coping were more likely to improve performance itself. The authors' analysis also revealed that the size of the training group was directly connected to the size of the effect. Stress inoculation training was found to be less effective at reducing state anxiety and enhancing performance with larger groups than with smaller groups. This pattern of outcome was not found to be true for the reduction of performance anxiety, on the contrary, the larger the training group, the greater the reduction in anxiety.

The findings from these reviews clearly suggest that stress inoculation is a very effective means of reducing subjective psychological distress and enhancing objective performance in some circumstances.

Stress Management Programs

Several studies have examined the effectiveness of stress management programs and found them to help reduce symptoms associated with stress (Bernier & Gaston, 1989; Saunders, Driskell, Johnston, & Salas, 1996; Zakowski, Hall, & Baum, 1992). Kagan, Kagan, and Watson (1995) implemented a psychoeducational stress management program to emergency medical service workers over a three-year period that included nine and 16 month follow ups. This rather extensive investigation demonstrated the positive effect of the program across a variety of domains to include measures of emotional health such as depression, anxiety, strain, depersonalization, and a sense of accomplishment as well as at least one measure of behavioral outcome—the number of commendation letters from customers doubled following the training. Murphy (1996) also investigated the efficacy of stress management programs. Following his 20-year review, encompassing numerous programs, he concluded that stress management approaches that combined techniques were most effective. Humara (2002) also conducted a review of such programs (for sports performance) and found several common mechanisms across the programs evaluated. The results of his review indicate that programs that included the following concepts tend to be the most effective at improving performance and reducing anxiety: goal-setting, positive thinking, situation restructuring, relaxation, focused attention, and imagery and mental rehearsal.

Other researchers have examined various components within these programs as mechanisms for stress reduction. Dandoy and Goldstein (1990) found that intellectualization statements resulted in positive coping. Specifically, these investigators showed that being exposed to statements that encouraged emotional detachment and analytical observation of explicit industrial accidents on videotape (i.e., table saw injury) lowered levels of physiological arousal in subjects and enhanced their recall of events. Shipley and Baranski (2002) investigated the effect of a visualization strategy (visuo-motor behavioral rehearsal) on stressful police scenarios. Visuo-motor behavioral rehearsal, like many other visualization techniques, requires individuals to imagine in vivid detail the perfect performance of some act, prior to engaging in the act. For example, using this strategy with a professional downhill skier would entail having him repeatedly practice a flawless run down the mountain. The protocol calls for as much detail and imaginal reality as possible to enhance the visualized experience. There are several theories as to why such techniques are effective. For example, some have posited that visualization can result in muscle contraction similar to that experienced in the actual performance of the act when the visualization is vivid and realistic. Other researchers argue that visualization provides a relaxed setting in which to practice and problem-solve performance prior to the actual event. This may reduce both the novelty of the situation and anxiety or stress otherwise associated with the performance. In the case of Shipley and Baranski's investigation, officers who used visualization techniques reported experiencing less anxiety and improved their performance in subsequent test scenarios. Caldwell (1997) determined that pilots were able to improve restfulness and restore their sleep patterns after using a self-administered relaxation therapy. He and his colleague have also shown that various pharmacological interventions, central nervous system stimulants, (Modafinil/Provigil R and Dextroamphetamine/Dexedrine R) can be incorporated into stress management procedures to improve performance, mood ratings, and physiologic measures of alertness (Caldwell, 2001; Caldwell & Gilreath, 2002).

Dutke and Stober (2001) determined that the adverse effect of stress on performance was ameliorated to some degree after individual motivation improved (motivation instruction was provided). Katz and Epstein (1991) found that individuals high in constructive thinking (solution-focused problem solving attitudes) tended to be less physiologically aroused by stress (performing calculation and visual tracking tasks with threats to self-esteem) and more positive emotionally and cognitively than those low in constructive thinking who were also exposed to stress. These authors concluded that the majority of stress one experiences is self-produced. Similarly, Ingledew, Hardy, and Cooper (1997) noted that as psychological stress increases, avoidance coping does as well. However, such strategies are less common in individuals with high internal strategies (i.e., cognitive reframing) and perceived social support. They found that strategies high in emotion-focused and problem-focused coping had the greatest positive effect. Such findings shed light on the cognitive appraisal mechanisms targeted in most stress management and inoculation programs. Taken collectively, these investigations suggest that stress management programs can indeed be effective, probably because of the cognitive and behavioral coping strategies they provide. For example, the ability to cognitively reconstruct one's appraisal of an event into less distressing terms may be one of these strategies. Furthermore, given that such appraisal is related to motivation and effort (perceiving an obstacle as a challenge tends to mobilize effort and motivation whereas viewing it as an overwhelming threat may have the opposite effect) it is easy to see why such an approach would be beneficial. Subsequent performance feedback that confirms success as a result may enhance the positive effects of the coping strategy leading to a greater sense of confidence and self-efficacy. In turn, self-efficacy affects one's perception of controllability and predictability and makes positive cognitive appraisal more likely. These events further reinforce the strategy used, making it more likely to occur under future conditions.

Critical Incident Stress Management / Psychological Debriefing

Critical incident stress management (CISM) is a procedure related to stress management and bears mention in this review. In some ways CISM is a hybrid of both stress inoculation and management programs. Typically, the model is geared toward first responders (similar to inoculation) but it is implemented de facto, following exposure to a stressful event or set of conditions (similar to stress management). Its purpose is to defuse or prevent the later development of acute as well as chronic stress reactions to critical or traumatic stressors. The model has been embraced by numerous organizations and is currently used extensively by law enforcement, fire fighting, emergency rescue, military, and airline industries. However, this intervention strategy has received only limited and recent empirical review, and the results are quite mixed.This technique, although related, should not be confused with Flanagan's Critical Incident Technique (Flanagan, 1954) or the subsequent knowledge elicitation methods used in cognitive task analysis (Hoffman, Crandall, & Shadbolt, 1998) that build from this earlier critical incident interviewing approach.

McNally, Bryant, and Ehlers (2003) provided an extensive review of the literature on CISM and the debriefings associated with this intervention. These authors raise several important questions regarding psychological interventions following traumatic events. Specifically, they target psychological debriefing methods: "…do psychological interventions delivered shortly after traumatic events mitigate distress and prevent later problems, especially PTSD? In particular, do trauma-exposed people who receive psychological debriefing—the most popular intervention—experience fewer difficulties than do people who are not debriefed?" (p. 46).

McNally and his colleagues (2003) provide operational definitions and descriptions of psychological debriefing, and they present several of the model's underlying assumptions. For example, the belief that it is better to commit to some form of catharsis—to talk about one's feelings rather than to keep those thoughts and emotions inside. Another is the assumption that the earlier the intervention, the better the outcome (believing that psychopathology can be "nipped in the bud" following a traumatic experience). As the authors aptly point out, these are empirical questions with no definitive answer at this time. However, they are alive and well (and affirmed) in the psychological debriefing model. The authors continue their review with a concise discussion of posttraumatic stress disorder (PTSD) and acute stress disorder (ASD) and a portion of their corresponding outcome literatures. Suffice it to say, having been exposed to a traumatic event does not predict with any certainly that one will suffer post-trauma pathology. In fact, in most instances the odds are clearly in one's favor for recovery and a return to functioning given time and the most basic levels of support (McNally et al., 2003).

McNally et al. (2003) trace the origins of psychological debriefing back to W.W.I at which time commanders gathered together combatants to debrief them and allow them to share their stories, creating a cohesive and collective experience. Such procedures have been continued throughout the twentieth century by military commanders (Litz, Gray, Bryant, & Adler, 2002), and this has expanded in recent decades to include a number of industries well beyond the military. An early champion of this movement was Jeff Mitchell who saw the connection between first responders (law enforcement, fire fighters, and emergency medical personnel) and the earlier combatants. He is typically credited as the first to introduce the concept of critical incident debriefing in his landmark paper on the subject two decades ago (Mitchell, 1983). Initially conceived as an individual or group model, geared toward first responders (i.e., EMS workers), and not the actual victims of trauma, critical incident stress debriefing (CISD) has evolved significantly. These rapid mutations have outstripped the research community's ability to evaluate the changes, and this is at the heart of the problem cited by McNally et al. (2003).

Various researchers have confirmed that most participants debriefed seem to perceive the experience as a positive one. Most recipients of psychological debriefings (98%) affirm that they feel better or feel that the debriefing was helpful in some way (Carlier, Voerman, & Gersons, 2000; Small, Lumley, Donohue, Potter, & Waldenstrom, 2000). Unfortunately, according to Carlier et al. (2000) there was no relationship between those that felt their debriefing was helpful and their psychological or functional health (as measured by the number of symptoms and continuation of work duties).

Several previous investigations have revealed disappointing results (Rose, Bisson, & Wessely, 2001; Rose, Brewin, Andrews, & Kirk, 1999; van Emmerik, Kamphuis, Hulsbosch, & Emmelkamp, 2002). Rose et al. (1999) explored the efficacy of single-session debriefings for victims of violent crime and concluded that there was no substantive support for such interventions. Conlon, Fahy, & Conroy (1999) examined the benefits of psychological debriefing in motor-vehicle accident survivors. They found no "prophylactic benefit" of psychological debriefing (p. 43). Furthermore, Rose et al. (2001) failed to discover any utility in CISD for the prevention of PTSD and openly criticized the notion of mandatory debriefings for trauma victims. Moreover, several studies support the negative effects of debriefings. Van Emmerik et al. (2002) conducted a meta-analysis of 29 studies using both individual and group intervention formats. Their review found that those debriefed were more likely to later develop PTSD symptoms than those that were not debriefed. Others have reached similar conclusions (Bisson, Jenkins, Alexander, & Bannister, 1997; Hobbs, Mayou, Harrison, & Worlock, 1996; Mayou, Ehlers, & Hobbs, 2000). According to McNally's group (2003), some investigators have presented positive results (Bohl, 1995; Everly & Mitchell, 1999; Wee, Mills, & Koehler, 1999); however, none of these studies used randomized trials and many have been open to criticism for various methodological problems.

The review by McNally and colleagues closes with an overview of findings, the main points of which I summarize here:

1) Mitchell and Everly (1999) criticize their critics for failing to investigate group debriefings (typically examining only individual debriefing models). This is a significant concern; however, McNally et al. (2003) contend that the underlying mechanisms shouldn't differ so greatly as to discount the findings that are limited to individual debriefing models. In addition, it should be noted that individual interventions remain a standard approach (one of the seven components) in CISM that is encouraged by the Mitchell model (Mitchell & Everly, 1998). Mitchell and Everly (1995) make it clear that CISD is "a group process" (p. 15), and, as such, any review of their model should contain group-debriefed outcome data. However, at least one recent investigation has addressed this criticism (van Emmerik et al., 2002).

2) Mitchell and Everly (1999) assert that psychological debriefing, as specified by their CISM model, reduces the likelihood of developing psychopathology following exposure to a critical incident. The randomly controlled trials in the research literature reviewed cast doubt on this assertion. Currently, very little is known experimentally regarding group debriefing outcomes.

3) Mitchell and Everly (1999) contend that CISD is not a stand-alone intervention. However, Mitchell (1983) previously indicated that single-session interventions were often sufficient for both prophylactic benefits as well as general symptom reduction. This seems contradictory.

4) Mitchell and Everly (1999) suggest that critics of CISD are failing to use the right outcome measurements, often choosing PTSD or depression measures instead of functional measures. However, Mitchell and Everly's own research findings as well as their claims made about CISD's ability to stave off PTSD symptoms seem to contradict this counter argument.

5) Mitchell has raised concerns that his critics have studied primary victims instead of secondary responders. This, too, seems inconsistent given the common advocacy for the models use with both primary and secondary victims.

6) Finally, McNally and his colleagues point out psychological debriefings, specifically Mitchell's model, have discounted review investigations that failed to adhere to the "letter of the law" in terms of CISD protocol. However, this seems to place the cart before the horse. No probative research has been leveled that sufficiently demonstrates Mitchell's particular model alone contains the underlying mechanisms related to efficacy.

The Speed / Accuracy Trade-Off Effect

Under the various stressors discussed previously, individuals tend to experience a speed/accuracy trade-off on cognitive measures whereby they tend to respond more quickly but create more errors (Fitts, 1966). This general finding appears across a wide variety of cognitive domains and under multiple sources of stress. Intuitively this makes sense as speed and accuracy are the two most accessible measures readily available to experimenters. Similarly, they represent a "teeter-totter" effect as movement in one, most often results in a corresponding movement in the other.

This effect has been reported under a number of conditions to include exposure to noise (Broadbent, 1957; Diaz, Hancock, & Sims, 2002; Hockey, 1979; Hygge & Knez, 2001), fatigue (Schellekens, Sijtsma, Vegter, & Meijman, 2000), time pressure (Driskell et al., 1992), the thermal stressors of heat and cold (Driskell et al., 1992), and group pressure (Driskell et al., 1992). Moreover, it has also been examined among varying contexts or tasks to include measures of visual search and attentional processing (Diaz, Hancock, & Sims, 2002; Hockey, 1979), memory (Hygge & Knez, 2001; Schellekens, Sijtsma, Vegter, & Meijman, 2000; von Wright & Vauras, 1980), signal detection (Wickens, 1992), reaction time tasks (Lulofs et al., 1981), and measures of personal confidence (Hockey, 1979). Driskell et al.'s (1992) meta-analysis also examined several cognitive measures across various putative stressors and found support for the speed/accuracy trade-off phenomenon.

Laboratory versus Real-World Research Designs

Most of the research studies reviewed relied on laboratory experimental paradigms. Few examined human performance in its dynamic naturalistic setting (judgment and decision making being one exception). Naturally, science has erred on the side of experimental rigor, which calls for controlled environments, careful manipulation of singular variables, and isolated effects. In truth, causality and the specific relationship between variables would be difficult to understand in any other context. As one can imagine, it would be nearly impossible to tease apart complex relationships when numerous confounding variables and conditions co-exist. The unfortunate consequence of this is that any conclusions we may form based on controlled laboratory studies may not generalize to real-world performance under stress.

Several authors have addressed this subject and have highlighted similar concerns. Baradell and Klein (1993) remarked, "Experimental stressors are temporary, often novel, and restricted in intensity, and usually have little long-term effect on the subject. Naturally occurring stressors tend to be more severe, recurring or continuous conditions that may have tremendous long-term effects on a person." (p. 267). Similarly, Morphew (2001) asserted that, "It has not been sufficiently demonstrated that the anxiety, fear, stress, uncertainty, risk, mental pressure, and arousal associated with performing in operational environments can be even generally approximated by laboratory-induced stressors." (pp. 255). Thus there is a disconnect between laboratory and real-world operational studies and outcomes. Woods and Patterson (2001) explored the cascading escalation of cognitive demands in real-world settings. They highlight the fact that such conditions typically do not occur in the laboratory. The authors argue that such escalation often results in a greater number of errors and that the expanding demands create opportunity for new demands and new errors. Therefore, real-world phenomena can not be considered a match for the "textbook case" when examined within an experimental laboratory setting.

Wilson, Skelly, and Purvis (1989) studied pilot's responses during actual versus simulated flight emergencies. They found a 50% increase in heart rate during real flight emergiencies as compared to simulated flight emergencies. Low-heart-rate variability, often associated with high stress and workload, was much more pronounced in the real situation than in the simulator. Their results indicate that significant changes related to performance can occur between real and simulated conditions. These findings are consistent with previous investigations into the difference between open water diving and chamber diving as well as shallow versus deep water diving. Mears and Cleary (1980) found that there was a perception of risk and danger associated with deeper water dives as compared to shallow or chamber dives. These perceptions resulted in performance decrements on measures of manual dexterity, physiological arousal (increased heart rate) and self-reported anxiety. Several previous investigations into this phenomenon confirm that there is a difference in perception and objective performance measures between real-world diving operations as compared to chambered diving (Baddeley, 1966; Baddeley & Fleming, 1967; Baddeley, DeFiguererdo, Hawkswell, & Williams, 1968).

McCarthy (1996) described G-LOC (the rate of change in velocity that induces a loss of consciousness) and the difference in research laboratory findings versus those in the real-world in terms of combat fighter pilot performance. The author noted that 99% of fighter pilots can sustain pressures of 9G's for about 15 seconds after training; however, G-LOC continues to be a problem and occurs at much lower G tolerances than demonstrated in the laboratory. McCarthy suggests that this is due to limited attentional resources. He cites that most individuals have a relaxed G tolerance of up to 5Gs. With the addition of the ATAGs flight suit (Advanced Technology Anti-G Suit), specially designed for increasing G tolerance, this figure rises to around 8Gs. He contends that operational workload reduces a pilot's ability to perform a focused AGSM (Anti-G Straining Maneuver) which in turn leads to G-LOC under conditions of less than 9Gs. The author found that test pilots have no problem handling the higher G load, nor do astronauts or stunt pilots (i.e., the Thunderbirds) due to their ability to focus on singular tasks. In each case their full attentional resources can be devoted to performing the AGSMs. However, the added complexity and higher workload of normal fighter operations can lead to reduced attention for AGSMs, and this leads to G-LOC and higher accident rates. McCarthy (1996) provides a compelling illustration of the disastrous impact that disconnections between laboratory and real-world research findings can have.

Several researchers have questioned the validity and generalizability of laboratory studies examining emotional memories. They have charged that such investigations typically expose subjects to unrealistic emotional stimuli. For example, Laney, Heuer, and Reisberg (2003) suggest that most laboratory studies examining the effects of emotion on memory employ gruesome images as to-be-remembered emotional material. In contrast to these visually-dominant displays, the authors argue that the emotion induced by natural events tends to be developmental (unfolding with the event) and rarely reflects the kind of visually shocking stimuli described above. In their own investigation of this issue, the authors found that most of the emotional memories recalled by subjects were categorized as thematic and not visual. This is in stark contrast to the type of visual display used by researchers to induce emotional memories in most laboratory studies. Given the findings that most emotional memories are thematic and not visual (80%), the authors suggested that previous laboratory paradigms have employed atypical emotional memory events. Laney et al. (2003) raise interesting questions about the generalizability of such laboratory findings. They suggest that the tunnel memory and "weapon focus" phenomena, robust among laboratory studies, should be evaluated using more naturalistic to-be-remembered stimuli. Furthermore, they propose that the effect of arousal, as Easterbrook (1959) and others have posited, may be an artifactual finding. Instead, what may underlie these phenomena are the saliency of the image and not necessarily the direct effects of arousal on cue sampling.

Kingstone, Smiek, Ristic, Frieden, and Eastwood (2003) argued that the field of cognitive psychology has "lost touch" with its origins as studies of real-world significance have been slowly replaced by artificial laboratory experiments that bear little if any generalizability to the real-world. The authors illustrate this point by reviewing a handful of naturalistic studies that have subsequently over-turned previously held positions in the field based on past laboratory findings. The authors report, "…the evidence suggests that laboratory studies that have lost touch with real-life context may generate fundamental misunderstandings of the principles of human attention and behavior." (p. 179). The authors call for future research to focus more on identifying which studies in the field are truly generalizable to the real-world and which are not.

There is yet a further point that deserves discussion here. It concerns the implementation of realistic stress manipulations in laboratory designs. The criticism has been leveled that stress manipulations used in experimental designs tend to be mild or moderate and rarely rise to the level experienced in real-world or naturalistic settings. Moreover, simulation studies may not effectively manipulate real-world levels of stress. This conclusion has lent support for the expression, "no one has ever died in a simulator." The reader will undoubtedly note that the research addressing stress effects on performance rarely includes adequate checks of its stress manipulations. Typically, researchers assume that they are increasing workload or stress, without measuring whether this is truly the case or not. Moreover, even when these checks are in place, the stressors used to evoke a change in performance rarely mimic the intensity or complexity of those experienced in a naturalistic setting. Finally, the most frequently used stress manipulation check is self-report, yet very little appears in the research literature concerning the validity of such measures and their sensitivity or participants' ability to discriminate between negative affective states (e.g., stress as compared to emotional discomfort or anxiety).

The Biology and Neuro-anatomy of the Human Stress Response

There is an entire domain of the stress and cognitive processing literature that this review has not thoroughly addressed. This domain includes: neuro-anatomical structures, subcortical and cortical functions (i.e., executive-prefrontal cortex literature), biochemical influences, and pharmacologic effects on cognitive performance while under stress. A brief review of these elements follows.

Several different avenues have been explored to explain the relationship between stress and cognitive process. The most commonly examined systems are those considered to be neuro-endocrine-based and include the pituitary-adrenocortical, adrenomedullary, and the sympathoneural systems. There have been few attempts to connect cognitive functions directly to neuro-anatomical structures or neural systems; yet most researchers agree that it is within such systems that cognitive processes lie. For example, many studies have implicated frontal lobe function and portions of the prefrontal cortex in the organization and prioritization of mental tasks (Borisyuk & Kazanovich, 2003; Vasterline, Brailey, Constans, & Sutker, 1998); however, researchers can only speculate as to how these processes occur, what generates their activity, and how they are organized and distributed cognitively.

Mills (1985) provided a review of the endocrine system and its response to various stressors. He reported that Cannon (1915) was the first to outline the 'emergency-function' theory of adrenal medullary activity—the sympathetic nervous system's fight or flight response using adrenaline. He suggested that, "conditions characterized by novelty, anticipation, unpredictability, and change produce a rise in adrenaline output which correlates with the degree of arousal evoked by the stressor…[however]…if the subject then gains control over the situation, adrenaline excretion falls." (p. 642.). Mills pointed out that physical stress elicits catecholamine production and its release, which has been shown to increase performance on certain tasks in terms of speed, accuracy, and endurance.

Several investigators have explored executive function as it relates to changes in information processing (Fowler, Prlic, & Brabant, 1994). For example, Russo, Escolas, Sing, Thorne, Johnson, Redmond, Hall, Santiago, and Holland (2002) implicated fatigue and sleep deprivation in the deactivation of portions of the prefrontal cortex. These authors examined the role of continuous flight operations and found that fatigue appears to result in a hypometabolism or deactivation of complex prefrontal attentional and prioritization regions in the brain. The prefrontal cortex may also play an important role associated with task-shedding as it is believed to relate to the organization of information and its coordinated distribution to other brain processing centers.

Various investigations have attempted to understand the organization of neural structures and corresponding biochemical systems that are related to the human stress response. Gray (1990) reviewed the neurobiological research and concluded that there was a strong link between cognition and emotion. He subsequently developed a model containing three fundamental emotion systems: the behavioral approach system (BAS), the fight/flight system (FFS), and the behavioral inhibition system (BIS). These basic response systems have been used extensively in work on pre-cognitive appraisal models such as the evaluative reflex (Duckworth, Bargh, Garcia, & Chaiken, 2002). Wofford and Daly (1997) have also put forth a cognitive-affective model of stress and coping connecting neural network and pathway theories with contemporary cognitive models of appraisal and attribution. Gaillard and Wientjes (1994) suggested that two types of energy mobilization systems were engaged in the human stress response: an effort system—dominated by the adrenal-medullary system and catecholamines (the autonomic nervous system)—and the distress system—dominated by the adrenal-cortical system and its agent, cortisol. Cacioppo (1994) reviewed the neurophysiological stress response of the autonomic nervous system, detailing the sympathetic neural activation system and the

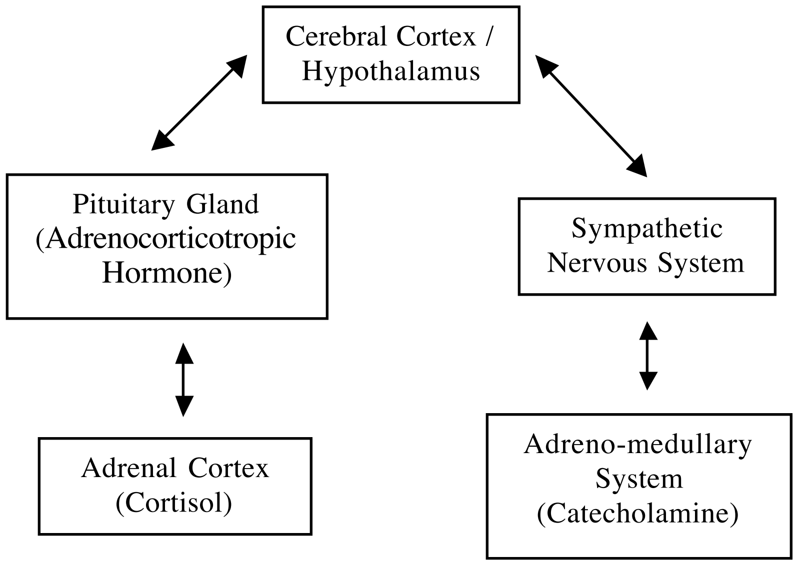

Figure 5: the figure above represents the neuro-physiological elements believed to be involved in the human stress response (Akil, Campeau, Cullinan, Lechan, Toni, Watson, & Moore, 1999; Cacioppo, 1994; Gaillard & Wientjes, 1994).

various physiologic responses associated with the activation of this system (heart rate, blood pressure, respiratory rate, perspiration, inhibition of digestive system and sexual functions). Akil, Campeau, Cullinan, Lechan, Toni, Watson, and Moore (1999) described the brain-pituitary-adrenocortical axis asserting its involvement in the regulation of glucocorticoid hormones implicated in the stress response.

Zeier (1994) found support for this connection when he compared self-reported and objective workload measures to salivary cortisol levels in an assessment of Air Traffic Controller tasks. His results suggest that workload and cortisol levels are highly correlated. Bohnen, Nicholson, Sulon, and Jolles (1991) investigated whether salivary cortisol secretion, as an index of stress on mental task performance, reflected individual differences in coping styles. Their findings suggest that cortisol levels are in fact a useful index of subjective stress and coping strategy. Furthermore, these authors determined that using cognitive affirmations and cognitive reframing strategies is useful in reducing cortisol levels as well as improving subjective stress ratings.

Al'Absi, Hugdahl, and Lovallo (2002) measured cortisol levels in subjects after they completed mental-arithmetic and public-speaking tasks. Their results indicated that high-cortisol responders performed worse than low-cortisol responders on mental arithmetic but better on dichotic listening. The authors suggested that the performance enhancement on dichotic listening may have resulted from a shift in focus of attention. Al'Absi, et al. reported that high-cortisol responders rated their moods more negatively than low-responders. This finding further links the relationship between perceived stress, cortisol activation, and performance. These investigators concluded that cortisol disrupts working memory but enhances selective attention. Newcomer, Selke, Nelson, Hershey, Craft, Richards, and Alderson (1999) examined the role of cortisol (simulating stress) in degrading memory function as well. They subjected individuals to cortisol levels consistent with the psychological stress response experienced pending surgical procedures. They found that exposure to cortisol levels induced by such stress results in a reversible decrease in verbal declarative memory. These authors measured verbal memory through an immediate and delayed paragraph-recall task. Both immediate and delayed recall was affected by the increase in cortisol. This decrement in performance was removed following a return to normality in cortisol blood levels. Performance was not found to be degraded significantly when assessing nonverbal memory, sustained or selective attention, and executive-function tasks (continuous performance task, spatial delay response task, and the Stroop color-word task).

Vedhara, Hyde, Gilchrist, Tytherleigh, and Plummer (2000) noted that student exam periods appeared to be related to an increase in self-reported stress; however, this corresponded unexpectedly to a decrease in cortisol levels. This profile was associated with an increase in short-term memory performance (hippocampal-specific) without the result of negative effects on auditory verbal working memory. Moreover, the increase in subjective levels of stress and decreased levels of salivary cortisol corresponded to degraded performance on measures of selective attention (telephone search task) and divided attention (telephone search and counting tasks). The authors concluded that cortisol is related to cognitive performance but that its effects are selective. Lupien, Gillin, and Hauger (1999) came to a similar conclusion after examining the effects of hydrocortisone on working memory. They found these effects to be acute for all but declarative memory performance, which may suggest a differential sensitivity to corticosteriods between memory systems.

In a related study, Diamond, Fleshner, Ingersoll, and Rose (1996) examined the relationship between stress, hippocampal impairment, and memory. The authors formulated a strong case for the connection between hippocampal function and memory. Furthermore, they empirically linked the hippocampus to regulatory functions over corticosterone receptors and ultimately behavioral responses to stress. Diamond et al. indicated that extended exposure to stress (and concomitantly to hypersecretion of cortisol), results in damage to the hippocampus (neural loss) and impairment in learning. In addition, these authors reported that such exposure has also been found to block hippocampal potentiation—often considered a central-feature in the modeling of memory from an electrophysiological perspective. In their investigation, Diamond et al. studied the effects of stress on hippocampal functioning in rats measured by performance on a maze task. The results of this investigation showed that after being placed in a stressful environment, a rat's working memory and its subsequent ability to learn was impaired. This effect was not found in measures of reference or long-term spatial memory. The authors concluded the hippocampal-specific learning (i.e., declarative memories) may be particularly sensitive to the effects of stress on working memory functioning.

Van Galen and van Huygevoort (2000) concluded that neuromotor noise, defined as, "…the random variation of individual moves around their group mean" (p. 154) was the primary source of human error under workload and time pressure conditions. These authors argued that such noise reflects a mismatch between an intended movement and the outcome of that movement. Their approach is somewhat unique among the literature in its attempt to link directly to neural function, specifically, the way in which neural signals are disrupted by neuromotor noise. They contend that motor behavior is an inherently noisy process (typified by variable and random motor signals in the brain and body) and that biophysical, biomechanical, and psychological factors contribute to such noise. Through repeated investigations, the authors found that psychological and physical stress resulted in, "…non-specific neural activation spreading" and that this tended to increase neuromotor noise, making error in motor movement more likely (p. 155). Mandler's (1979) work is certainly consistent with the notion that cognitive noise absorbs available resources. He proposed that autonomic activity, resulting from stress, demands cognitive resources and attentional capacity. He labeled this autonomic activity "cognitive noise," due to its ability to draw away an individual's attention from primary task demands. Mandler examined the role of experience and mastery in performance in light of Easterbrook's cue utilization hypothesis. He affirmed the role of appraisal in the creation of subjective stress; however, he suggested stress created noise in the cognitive system which competed for a pool of limited mental resources. Van Gemmert and Van Galen (1997) share Mandler's view (1979), contending that this noise in the cognitive system results in either a reduced sensitivity to task-related sources of information or less exacting motor movements.

Biondi and Picardi (1999) provided the most thorough review of research examining the relationship between stress, cognitive appraisal, and neuroendocrine function. They found that one's subjective perception of a stressful situation resulted in various psycho-endocrine response patterns, specifically, modulations among the pituitary-adrenocortical, adrenomedullary, and the sympathoneural systems. They reported that mental arithmetic was perhaps the most commonly examined stressor in this literature and that it has been demonstrated repeatedly to induce elevations in plasma catecholamine levels such as epinephrine and norepinephrine. More specifically, their review of the literature suggested that these elevations resulted primarily from adrenal medulla and sympathetic nerve terminal releases. Mental arithmetic stress has frequently been combined with that of public speaking. This combination has been found to result in the addition of an adrenocortical activation (typically measured in salivary cortisol levels) as well. Similar results have been reported in Stroop color-word conflict examinations and under prolonged laboratory cognitive tasks. In fact, various investigations have shown that the more demanding the cognitive task, the greater the elevations of epinephrine and cortisol released. However, this pattern has not been observed among more pleasant emotional experiences. For example, under conditions of videogame playing, significant adrenomedullary activation does not occur, although some increases in norepinephrine have been measured.

Although there has been some concern over the generalizability of laboratory findings to real-world experience in the area of human physiology (Dimsdale, 1984), Biondi and Picardi (1999) indicated that a consistent pattern of increased adrenaline, noradrenaline, and cortisol secretions have been found in both. In summarizing the findings associated with bereavement, these authors reported general agreement in the notion that adrenocortical activity is altered in many cases (i.e, increased levels of cortisol release). This appears to be the case particularly in instances where levels of anxiety and depression are greatest. Periods of test and examination have been researched by many, and this literature also points to altered levels of catecholamines as is the case with research on the anticipation of surgical interventions. In studies examining the immediate threat presented by parachute jumping, researchers have found a consistent pattern of an initial increase in cortisol levels as well as ACTH (adrenocorticotropic hormone) prior to the jump with an equal or greater release of adrenocortical activation following the jump.

According to Biondi and Picardi (1999) several lines of research have investigated the influence of coping strategies on hormone response. There is some data to support the notion that problem-focused interventions reduce psychoendocrine activity while avoidant or denial coping strategies actually tend to increase this response. The authors point out that these findings are modulated by the effectiveness of each strategy, implying that avoidant styles may in fact be less effective at dealing with stress than those that attempt to fix the problem directly. They concluded that these patterns appear to suggest that one's appraisal is a "main determinant of the psychoendocrine response…" (p. 139). Ennis, Kelly, Wingo, and Lambert (2001) also examined neuro-endocrine activity and its relationship to cognitive appraisal. They determined that the sympathetic neuro-endocrine system output increased differentially in individuals who perceived a test as threatening compared to those who viewed it as a challenge.

Farrace, Biselli, Urbani, Ferlini, and De Anelis (1996) found an increase in post-flight hormonal levels in student pilots (measured by growth hormone, prolactin, and cortisol) as compared to pre-flight levels. Instructor pilots demonstrated elevations only in growth hormone. Student pilots were also found to have significantly higher pre-flight levels of these hormones as compared to their instructors. These findings seem to suggest that experienced pilots may incur physiological arousal during flight but not the emotional arousal of students. Additionally, they may lack the anticipatory arousal incurred by student pilots.

Critchley and Mathias (2003) found a physiological correlate among Air Traffic Controller and driver performance on measures of attention and reaction time. Moderate hypotension was associated with decreases in behavioral measures. The authors cite work using neuroimaging that has explored the relationship between arousal and regional brain activity. They noted that previous findings indicate that blood pressure tends to increase after performing certain cognitive and motor tasks that are associated with stress and workload. These events coincide with anterior cingulate activity (located in the medial portion of the frontal lobe). Given research that has linked frontal lobe activity with attention and reaction time (Braver, Barch, Gray, Molfese, & Snyder, 2001) the authors speculate a relationship between hypotension and attentional control may implicate arousal-dependent processes as the underlying mechanism.

Matthews (2001) has suggested that neuroscience has taught us at least two important things about the relationship between mental resources and information processing. First, biologic agents such as drugs, hormones, neurotransmitters, and processes such as circadian rhythms clearly affect performance. Second, psychophysiological measures have provided information about performance and the human stress response. However, he also outlined several shortcomings with biological models. For example, debate continues as to the identification of specific neural systems implicated in the mediation of biological stressors. There is very little information on real-world experiences and their neural response. Neuroscientists have failed to provide us with strong biological models of personality and individual difference factors, and finally, we still have many central unanswered questions concerning cognition and information processing.

Limitations of the Review and Questions left Unanswered

There are a number of limitations that bear mentioning concerning this review. The first is that while I have attempted to be as inclusive as possible, there are undoubtedly portions of the research literature I have completely ignored as well as others of which I have only tapped the surface. As has already been stated, the majority of this review is based on a synthesis of previous reviews and as such is a reflection of what these previous reviews have addressed as well as what these reviews have neglected. Furthermore, many of the putative stressors examined—such as noise, thermals, fatigue, and others—have voluminous literatures of their own. No attempt was made to cover these areas in any depth. Instead the review selected a handful of studies that are believed to be representative of much larger literatures providing a general overview of pertinent findings.

In similar fashion, there are other cognitive processes beyond those covered within this review that deserve acknowledgment. For example, there is a significant literature addressing the effects of stress on language and communication (French, 1983). In addition, there are bodies of work on thought suppression and distraction or interference processes that address stress-specific effects and not just those related to dual-task performance (Keinan, Friedland, Kahneman, & Roth, 1999). There is a large research literature that has examined social dynamics and team performance among the social and industrial/organizational psychology communities as well. The interested reader is referred to these areas for further review accordingly.

There are many questions that have been left unanswered by the research community. As in most areas of science, it seems that the more one learns about a complex human system the more one realizes how little is really understood about that system. Furthermore, such inquiry seems to frequently result in more questions being raised than answered. Many of these are questions that our field is currently ill-equipped to answer. I have provided a table outlining several of these questions that my review of the research literature on human performance and stress could not answer, at least not in depth.

Table 9. Questions that Remain Unanswered.

What is stress and can we measure it? Do all stressors create the same physiological pattern? If not, why not, and in what way do they differ? What is the mechanism that facilitates these differences? Is there a unitary mechanism that underlies the human stress response such as arousal? Are there several different systems?
What causes cognitive or information processing decrements? Are these the result of the direct effects of arousal or some other physiological system? What are the boundaries of impairment for each cognitive process and each stressor?
Why does positive appraisal improve performance? Are the positive effects of appraisal related to effort and mobilization? What mechanism is activated differently when viewing a stressor as a challenge as opposed to an overwhelming threat?
Why do various external stressors (heat, cold, noise, fatigue, etc.) cause decrements? Are these due to direct or indirect effects, or both? For example, are thermals (heat and cold) merely an irritant that plays into focus and motivation, or do they operate on physiological or thermodynamic principles to degrade performance? How can we systematically separate and measure these two types of effects to better understand their relative contributions?
Where do psychological resources come from? Are they a static pool upon which we draw? Are they called up via physiological responses (arousal/activation hypothesis) as described in the traditional fight/flight models? Are they limited in capacity? Is this just a regulation-of-attention problem? Are the cognitive structures associated with information processing the resources described by others, or do they simple require resources to process?
To what degree are top-down processes engaged in information processing and to what degree are bottom-up processes involved? In other words, are resources drawn and pulled by stimuli or directed by executive functions? Does this depend on the process, the task, or both? What is the nature of the central executive or homunculus function in the allocation or resources and other processes?
Is attention the primary gatekeeper for all other information processing decrements? For example, can working memory resources or capacity be diminished directly or are such deficits the result of earlier effects on attention? Similarly, does psychological stress inhibit attention, and thus cause memory to be degraded (encoding is disrupted), does it interfere with the quality of what is encoded (bad in = bad out), does it disrupt maintenance functions (i.e., rehearsal), or simply make retrieval more difficult in some other way?
Are biases in attention toward threat-related cues a function of trait, state, or a different underlying mechanism? Do these biases result in preferential orienting, difficulties disengaging, more depthful processing, or a combination of effects?
Are performance decrements that result from stress and/or workload catastrophic or gradual? Does this correspond to physiological changes that are catastrophic or gradual? Does this depend on the task? Does this depend on the source of the stress? When task-shedding occurs, which tasks are abandoned? At what point are they resumed? Why are some tasks protected and others shed?

Can we map the cognitive architecture of the human stress response to a neuro-biological basis? Are there corresponding neuro-anatomical structures that support our divisions of labor and projections of relationship? Will this provide us a definitive answer as to what resources really are? Are neuroendocrine and biochemical correlates causal agents or just transmission agents?
Well-learned tasks are generally resistant to stressors as compared to newly learned tasks (this is true of implicit material as compared to explicit). Why? Does it depend upon which type of task or which type of stressor?
What are the protective factors against stress and how do they work? What are the underlying mechanisms that explain how they operate?
Why do various moderating variables change the way putative stressors affect performance and cognition? Do they work off of a common mechanism such as effort or motivation or are there different mechanisms that explain their effects?

The Conceptual Framework of Information Processing under Stress

I present here, and in appendices A–E, a brief sketch of a conceptual framework of information processing under stress (Staal, Nowinski, Holbrook, & Dismukes, in preparation). As with any such model its benefits are descriptive and not predictive. This framework is an instantiation of the transactional perspective and is generally consistent with previous models (e.g. Hancock & Warm, 1989; Matthews, 2002; Park & Folkman, 1997). It is also grounded in well-established and accepted cognitive architectural principles (Anderson, 2000; Lebiere & Anderson, 2001). However, while attempting to accommodate previous frameworks, it also extends beyond these in attempting to integrate various perspectives and bodies of information.

This framework relies on several assumptions that have been drawn from the existing cognitive science literature. It does not assert a unique mechanism or explanation for the nature of resources nor does it attempt to displace existing explanations beyond that which has been provided by the literature review, concerning arousal, effort, or other activation-based theories of energy mobilization. The model does assume that energy mobilizations typically occur under one of two conditions: 1) task-induced situations (activation results from the stimulation of the task or environment itself), and 2) internally-guided mental effort (a voluntary mobilization). This set of assumptions is somewhat distinctive from traditional resource theories (Kahneman, 1973; Wickens, 1992), as it emphasizes regulatory processes and not the availability of supplies. Accordingly, the framework contends that activation and energetical processes can be allocated, controlled, and subject to resource management decisions. Moreover, this model assumes that behavior is largely goal-directed and self-regulated and that this regulation incurs costs to various portions of the processing system (i.e., further resources can be acquired at the expense of increased effort). These additional assumptions rest predominantly in the work of Hockey (1997) and Gaillard (2001). It should be noted, however, that these propositions are not in conflict with a strictly bottom-up-driven processing model either, and it is believed that both processes play a role in information processing under stress.

This construction assumes a transactional model of cognitive appraisal. As the reader may recall, transactional models view stress as the interaction between the environment and individual, emphasizing the role of appraisal in designing a response to stress (Lazarus, 1966; Lazarus & Folkman, 1984; McGrath, 1976). Thus, to a certain degree, cognitive mediation is required for perceptions of threat, fear, or anxiety, particularly in the later stages of the initial stress response. Prior to such processing, this model also assumes that an early, likely "hard-wired" and subcortical evaluation occurs after orienting to a given stimulus (Crawford & Cacioppo, 2002; Duckworth, Bargh, Garcia, Chaiken, 2002; Rohrbaugh, 1984). This initial evaluation is believed to be rooted in bio-evolutionary mechanisms and as a result occurs prior to conscious awareness (perhaps arguably at a pre-cognitive level).

Following this initial stage of recognition, evaluation, and higher-order appraisal, information regarding the stimulus and one's response feeds back into the system. As a result, there is an activation and mobilization of resources. These resources are both drawn and directed toward further processing of the stimuli. This process is moderated by various influences such as goal structure, motivation, and effort as well as individual difference characteristics and previous experience and learning. Continued information processing is accompanied by further appraisal and evaluation that periodically feeds back into the process. Such continuous input and situation assessment updates provide adjustments to resource allocation and processing accordingly. This process is believed to be similar to what has been described in the situation models literature (Zwaan & Madden, 2004; O'Brien, Cook, & Peracchi, 2004), and that encapsulated by research on situation assessment and awareness (McCarley, Wickens, Goh, & Horrey, 2002; Uhlarik & Comerford, 2002; Wickens, 2002). As this processing directs and draws attention, the effects of stress and workload impinge on the resources available for processing. This can result from a number of factors including resource-depletion and re-allocation. For example, emotion or threat-based cognitions (i.e., anxious thoughts) may re-distribute resources away from a task-relevant response or may simply consume or occupy them, resulting in fewer available resources to devote elsewhere (Ashcraft, 2002; Ashcraft & Kirk, 2001; Eysenck & Calvo, 1992).

The general effect of both psychological stress as well as high degrees of workload on attentional processing tends to be a reduction in the processing of peripheral information and an enhanced focus on centralized cues (Chajut & Algom, 2003; Easterbrook, 1959). The determinant between central and peripheral stimuli seems to be based on which stimulus is perceived to be of greatest importance to the individual or that which is perceived as most salient. Salience, from this perspective, may relate to distinctiveness as well as emotional valence (i.e., threat relevance). In some circumstances, filtering out peripheral cues is beneficial to performance and in other instances it is detrimental. From the perspective of this framework, attentional processing has been positioned as a conduit between cognitive appraisal and the direct effects of stress on information processing and later processes such as memory and decision making.

The basic mechanism by which stress affects memory performance is posited as the siphoning of attentional resources (Berntsen, 2002; Christianson, 1992). The extent to which a given memory process is affected is determined by the extent to which that memory process is attention-demanding (and the extent to which a stressor is attention-demanding). Encoding, rehearsal, and effortful retrieval of memory are all impaired under conditions of stress while well-learned behaviors and retrieval of information from long-term memory remain relatively intact.

It seems obvious that all information processing requires some amount of mental resources to occur. This allocation and use of resources begins at the appraisal process itself. Once a situation has been identified as threatening, rumination may begin to intrude upon an individual's thoughts. These worries occupy attentional resources that are necessary for other cognitive processing (Metzger, Miller, Cohen, & Sofka, 1990). In particular, it seems that worry intrudes on processing of verbal information (Ikeda, Iwanaga, & Seiwa, 1996; Rapee, 1993). Further, such negative thoughts perpetuate themselves by supporting involuntary retrieval of other anxious thoughts through their association in memory (Bower, 1981). Some individuals in certain situations may feel compelled to suppress an expression of their emotional response to stress. This activity, like rumination, requires the involvement of cognitive resources, leaving fewer resources available for other information processing (Richards & Gross, 2000; Richards, Butler & Gross, 2003). The amount of resources pre-empted by each action is believed to be quite variable. For instance, proceduralized tasks require few limited resources while novel or complex tasks require many more (Beilock, Carr, MacMahon, & Starkes, 2002).

The allocation of remaining available resources means that there are fewer left to devote to the processing of other stimuli. Working memory capacity is therefore effectively reduced (Burrows, 2002). Attentional resources are required to maintain information in working memory through rehearsal. As mentioned above, it seems to be the case that rumination interferes with phonological rehearsal of information in particular, leaving verbal information particularly vulnerable. Encoding and rehearsal of long-term memory are also negatively affected, as both are resource-demanding activities. Thus, information, other than that considered most salient, is not encoded as deeply or rehearsed as frequently. Subsequently, its recollection and recognition is likely to be reduced in both quantity and quality.

Retrieval from long-term memory should be relatively unaffected as it is not generally resource-demanding. Well-learned information, such as that associated with procedures or skills, is retrieved relatively automatically. However, several researchers have made a distinction between the processes involved in familiarity and recollection (Jacoby, 1991; Kensinger & Corkin, 2003). Familiarity occurs automatically, while recollection involves a more effortful process. Retrieval of ingrained knowledge from long-term memory should not be diminished under conditions of stress. However, more involved retrieval from long-term memory, that which requires an active search of memory, should show deficits in stressful situations.

Once accounting for diminished capacity, the direct effects of stress on attentional processing, and the subsequent effect on working memory, it is not difficult to understand why decision making is often compromised and concurrent task management degraded. As resources are ultimately used to capacity individuals must voluntarily or involuntarily shift strategies. Such shifts include the shedding of tasks as well as their simplification.

Appendices A through E provide a schematic representation of each component part among the three phases of processing, sense making, resource management, and performance. Appendix A presents an overview of cognitive appraisal processing elements while appendix B provides a review of a cognitive stress intervention model. Appendix C details the processing framework associated with attention and memory while appendices D and E integrate the framework's component parts in both simplified and in detailed arrangement.

References

Abela, J.R.Z., & Alessandro, D.U. (2002). Beck's cognitive theory of depression: A test of the diathesis-stress and causal mediation components. *The British Journal of Clinical Psychology, 41*, 111–128.

Ackerman, P.L., & Kanfer, R. (1994). *Improving problem-solving and decision-making skills under stress: Prediction and training*. (*Report No. 94.01*). Arlington, VA: Office of Naval Research.

Adelson, R. (2003). Driven to distraction. *Monitor, 34*(8), 24.

Ainsworth, L.L., & Bishop, H.P. (1971). *The effects of a 48-hour period of sustained field activity on tank crew performance* (HumRRO TR No. 71-16). Alexandria, VA: Human Resources Research Organization.

Akil, H., Campeau, S., Cullinan, W. E., Lechan, R. M., Toni, R., Watson, S. J., & Moore, R. M. (1999). Neuroendocrine Systems I: Overview, Thyroid and Adrenal Axes. In F. E. Bloom, S. C. Landis, J. L. Roberts, L. R. Squire, & M. J. Zigmond (Eds.), *Fundamental neuroscience* (pp. 1127–1150). New York: Academic Press.

Al'Absi, M., Hugdahl, K., & Lovallo, W. R. (2002). Adrenocortical stress responses and altered working memory performance. *Psychophysiology, 39*, 95–99.

Allen, R.W., Magdaleno, R.E., & Jex, H.R. (1975). *Effects of wideband auditory noise on manual control performance and dynamic response* (AMRL-TR-75-65). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Allnut, M. (1982). Human factors: Basic principles. In R. Hurst, & L.R. Hurst (Eds.), *Pilot error* (pp. 1–22). New York: Aronson.

Alluisi, E.A., & Fleishman, E.A. (1982). *Human performance and productivity: Stress and performance effectiveness*. Hillsdale, NJ: Erlbaum.

Allport, D.A. (1980). Attention and performance. In G. Claxton (Ed.), *Cognitive psychology: New directions* (pp. 112–153). London: Routledge & Kegan Paul.

Allport, D.A., Antonis, B., & Reynolds, P. (1972). On the dividsion of attention: A disproof of the single-channel hypothesis. *Quarterly Journal of Experimental Psychology, 24*, 225–235.

Altmaier, E., Ross, S., Leary, M., & Thornbrough, M. (1982). Matching stress inoculations' treatment components to client's anxiety mode. *Journal of Counseling Psychology, 29*, 331–334.

Anderson, J.R. (2000). *Cognitive psychology and its implications 5th Ed*. New York: Worth.

Andre, A.D. (2001). The value of workload in the design and analysis of consumer products. In P.A. Hancock, & P.A. Desmond, *Stress, workload, and fatigue* (pp. 373–382). Mahwah, NJ: L. Erlbaum.

Arnsten, A.F.T., & Goldman-Rakic, P.S. (1998). Noise stress impairs prefrontal cortical cognitive function in monkeys. *Archives of General Psychiatry, 55*, 362–368.

Ashcraft, M. H. (2002). Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science, 11*, 181–185.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General, 130*, 224–237.

Atkinson, R.C., & Shiffrin, R.M. (1968). Human memory: A proposed system and its control processes. In K.W. Spence (Ed.), *The psychology of learning and motivation: Advances in research theory* (pp. 89–195). New York: Academic Press.

Auerbach, S.M., Martelli, M.F., & Mercuri, L.G. (1986). Anxiety, information, interpersonal impacts, and adjustment to a stressful health care situation. *Journal of Personality and Social Psychology, 44*, 1284–1296.

Averill, J.R., & Rosen, M. (1972). Vigilant and nonvigilant coping strategies and psychophysiological stress reactions. *Journal of Personality, 23*, 128–141.

Backs, R.W. (2001). An autonomic space approach to the psychophysiological assessment of workload. In P.A. Hancock, & P.A. Desmond, *Stress, workload, and fatigue* (pp. 279–289). Mahwah, NJ: L. Erlbaum.

Bacon, S.J. (1974). Arousal and the range of cue utilization. *Journal of Experimental Psychology, 102*(1), 81–87.

Baddeley, A.D. (1966). Influence of depth on the manual dexterity of free divers: A comparison between open sea and pressure chamber testing. *Journal of Applied Psychology, 50,* 81–85.

Baddeley, A.D. (1972). Selective attention and performance in dangerous environments. *British Journal of Psychology, 63*(4), 537–546.

Baddeley, A.D. (1986). *Working memory*. Oxford, England: Oxford University Press.

Baddeley, A.D. (2002). Is working memory still working? *European Psychologist, 7*(2), 85–97.

Baddeley, A.D., DeFiguererdo, J.W., Hawkswell, C., & Williams, A.N. (1968). Nitrogen narcosis and performance underwater. *Ergonomics, 11*, 157–164.

Baddeley, A.D., & Fleming, N.C. (1967). The efficiency of divers breathing oxy-helium. *Ergonomics, 10*, 311–319.

Baddeley, A.D., & Hitch, G.J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (pp. 47–90). San Diego, CA: Academic Press.

Baddeley, A.D., & Hitch, G.J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*(4), 485–493.

Baddeley, A.D., Lewis, V., Elderidge, M., & Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 13*, 518–540.

Badia, P., Culbertson, S. (1970). Behavioral effects of signaled vs. unsignalled shock during escape training in the rat. *Journal of Comparative and Physiological Psychology, 72*, 216.

Bahrick, H.P., Clark, S., Bahrick, P. (1967). Generalization gradients as indicants of learning and retention of a recognition task. *Journal of Experimental Psychology, 75*(4), 464–471.

Banich, M., Stokes, A.F., Elledge, V. (1987). *Cognitive function evaluation in the medical certification of airmen: A literature review*. Savoy, IL: University of Illinois Aviation Research Laboratory.

Banks, J.H., Sternberg, J.J., Farrell, J.P., Debrow, C.H., & Dalhamer, W.A. (1970). *Effects of continuous military operations on selected military tasks* (BESARL TR No. 1166). Arlington, VA: U.S. Army Organizational and Systems Research Laboratory.

Baradell, J.G., & Klein, K. (1993). Relationship of life stress and body consciousness to hypervigilant decision making. *Journal of Personality and Social Psychology, 64*(2), 267–273.

Baranski, J. V., Gil, V., McLellan, T. M., Moroz, D., Buguet, A., & Radomski, M. (2002). Effects of modafinil on cognitive performance during 40 hr of sleep deprivation in a warm environment. *Military Psychology. 14*, 23–47.

Bargh, J.A., Chaiken, S., Govender, R., & Pratto, F. (1992). The generality of the automatic attitude activation effect. *Journal of Personality and Social Psychology, 62*, 893–912.

Bargh, J.A., Chaiken, S., Raymond, R., & Hymes, C. (1996). The automatic evaluation effect: Unconditional automatic attitude activation with a pronunciation task. *Journal of Experimental Social Psychology, 32*, 104–128.

Barnard, P.J., & Teasdale, J.D. (1991). Interacting cognitive subsystems: A systemic approach to cognitive-affective interaction and change. *Cognition and Emotion, 5*(1), 1–39.

Baron, R.S. (1986). Distraction-conflict theory: Progress and problems. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (pp. 1–40). New York: Academic Press.

Bar-Tal, Y., Raviv, A., & Sptizer, A. (1999). The need and ability to achieve cognitive structuring: Individual differences that moderate the effect of stress on information processing. *Journal of Personality and Social Psychology, 77*(1), 33–51.

Barthol, R.P., & Ku, N.D. (1959). Regression under stress to first learned behavior. *Journal of Abnormal and Social Psychology, 59*, 134–136.

Bartlett, F.C. (1953). Psychological criteria for fatigue. In W.F.Floyd & A.T. Welford (Eds.), *Symposium on fatigue*. Londong: H.K. Lewis.

Baum, A., & Paulus, P. (1987). Crowding. In D. Stokols & I. Altman (Eds.), *Handbook of environmental psychology* (pp. 533–570). New York: Wiley.

Beatty, J. (1982). Task-evoked pupillary response, processing load, and the structure of processing resources. *Psychological Bulletin, 91*, 276–292.

Beck, A.T. (1976). *Cognitive therapy and the emotional disorders*. New York: International Universities Press.

Beck, A.T. (1987). Cognitive models of depression. *Journal of Cognitive Psychotherapy, 1*, 5–37.

Beier, E.G. (1951). The effects of induced anxiety on flexibility of intellectual functioning. *Psychological Monographs, 65*, 326.

Beilock, S. L., Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*, 701–725.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied, 8*, 6–16.

Bell, P., & Greene, T. (1982). Thermal stress: Physiological comfort, performance, and social effects of hot and cold environments. In G.W. Evans (Ed.), *Environmental stress*. New York: Cambridge University Press.

Ben Zur, H., & Breznitz, S.J. (1981). The effects of time pressure on risky choice behavior. *Acta Psychologica, 47*, 89–104.

Bergh, U. (1980). Human power at subnormal body temperatures. *Acta Physiologica Scandanavica, 478*, 1–39.

Bernier, D., & Gaston, L. (1989) Stress management: A review. *Canada's Mental Health, 37*, 15–19.

Berntsen, D. (2002). Tunnel memories for autobiographical events: Central details are remembered more frequently from shocking than from happy experiences. *Memory & Cognition, 30*, 1010–1020.

Biondi, M., & Picardi, A. (1999). Psychological stress and neuroendocrine function in humans: the last two decades of research. *Psychotherapy and Psychosomatics, 68*, 114–150.

Bisson, J.L., Jenkins, P.L., Alexander, J., & Bannister, C. (1997). Randomised controlled trial of psychological debriefing for victims of acute burn trauma. *British Journal of Psychiatry, 171*, 78–81.

Bistline, J.L., & Frieden, F.P. (1984). Anger control: A case of a stress inoculation treatment for a chronic aggressive patient. *Cognitive Therapy & Research, 8*, 551–556.

Blake, M.J.F. (1967). Time of day effects on performance in a range of tasks. *Psychonomic Science, 9*, 349–350.

Boggs, D.H., & Simon, R.S. (1968). Differential effect of noise on tasks of varying complexity. *Journal of Applied Psychology, 52,* 148–153.

Bohl, N. (1995). Measuring the effectiveness of CISD: A study. *Fire Engineering, 148*, 125–126.

Bohnen, N., Nicolson, N., Sulon, J., & Jolles, J. (1991). Coping style, trait anxiety and cortisol reactivity during mental stress. *Journal of Psychosomatic Research, 35*(2/3), 141–147.

Bond, C.F. (1982). Social facilitation: A self-presentational view. *Journal of Personality and Social Psychology, 42,* 1042–1050.

Bond, C. F., & Titus, L. J. (1983). Social facilitation: A meta analysis of 241 studies. *Psychological Bulletin, 94*(2), 265–292.

Borisyuk, R.M., & Kazanovich, Y.B. (2002). Oscillatory neural network model of attention focus formation and control. *BioSystems, 71,* 29–38.

Bourne, L.E., & Yaroush, R.A. (2003). *Stress and cognition: A cognitive psychological perspective*. Unpublished manuscript, NASA grant NAG2-1561.

Bower, G.H. (1981). Mood and memory. *American Psychologist, 36*, 129–148.

Bowers, K. (1968). Pain, anxiety, and perceived control. *Journal of Clinical and Consulting Psychology, 32*, 295–303.

Bowers, C., Salas, E., Asberg, K, Burke, S., Priest, H., & Milham, L. (2002). *Combat readiness and stress: Laboratory investigations of teams*. DoD Multidisciplinary Research Program: MURI Operator Performance Under Stress (OPUS).

Bowles, S., Ursin, H., & Picano, J. (2000). Aircrew perceived stress: Examining crew performance, crew position, and captains personality. *Aviation, Space, & Environmental Medicine, 71*, 1093–1097

Braunstein-Bercovitz, H. (2003). Does stress enhance or impair selective attention? The effects of stress and perceptual load on negative priming. *Anxiety, Stress, and Coping, 16*(4), 345–357.

Braunstein-Bercovitz, H., Dimentman-Ashkenazi, I., & Lubow, R. E. (2001). Stress affects the selection or relevant from irrelevant stimuli. *Emotion, 1*, 182–192.

Braver, T.S., Barch, D.M., Gray, J.R., Molfese, D.L., & Snyder, A. (2001). Anterior cingulate cortex and response conflict: Effects of frequency, inhibition and errors. *Cerebral Cortex, 11*, 825–836.

Broadbent, D.E. (1951). The twenty dials test and the twenty lights test under noise. MRC/APRU res. Rep. 160–51.

Broadbent, D.E. (1954). Some effects of noise on visual performance. *Quarterly Journal of Experimental Psychology, 6*, 1–5.

Broadbent, D.E. (1958). *Perception and communication*. London: Pergamon.

Broadbent, D.E. (1963). Differences and interactions between stresses. *Quarterly Journal of Experimental Psychology, 15*, 205–211.

Broadbent, D.E. (1971). *Decision and Stress*. London: Academic Press.

Broadbent, D.E. (1978). The current state of noise research: Reply to Poulton. *Psychological Bulletin, 85*, 1052–1067.

Broadbent, D.E. (1979). Human performance and noise. In C.M. Harris (Ed.), *Handbook of noise control* (pp. 17.1–17.20). New York: McGraw-Hill.

Broadbent, D.E., & Broadbent, M. (1988). Anxiety and attentional bias: State and trait. *Cognition and Emotion, 2,* 165–183.

Broadbent, D.E., & Gregory, M. (1963). Vigilance considered as a statistical decision. *British Journal of Psychology, 54*, 309–323.

Broadbent, D.E., & Gregory, M. (1965). Effects of noise and signal rate upon vigilance analysed by means of decision theory. *Human Factors, 7,* 155–162.

Broadhurst, P. L. (1957). Emotionality and the Yerkes-Dodson law. *Journal of Experimental Psychology, 54*, 345–352.

Broder, A. (2000). Assessing the empirical validity of the "Take-the-Best" heuristic as a model of human probabilistic inference. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1332–1346.

Broder, A. (2003). Decision making with the "adaptive toolbox": Influence of environmental structure, intelligence, and working memory load. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(4), 611–625.

Brookhuis, K.A., & de Waard, D. (1993). The use of psychophysiology to assess driver status. *Ergonomics, 39*, 1099–1110.

Brookhuis, K.A., & de Waard, D. (2001). Assessment of driver's workload: Performance and subjective and physiological indexes. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Brookings, J.B., Wilson, G.F., & Swain, C.R. (1986). Psychophysiological responses to changes in workload during simulated air traffic control. *Biological Psychology, 42*(3), 361–377.

Brown, I.D. (1994). Driver fatigue. *Human Factors, 36*, 298–314.

Brown, W.P.I. (1965). The Yerkes-Dodson law repealed. *Psychological Reports, 17*, 663–666.

Buck-Gengler, C. J., & Healy, A. F. (2001). Processes underlying long-term repetition priming in digit data entry. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 879–888.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review, 97*, 523–547.

Burger, J.M., & Arkin, R. (1980). Prediction, control, and learned helplessness. *Journal of Personality and Social Psychology, 38*, 482–491.

Burke, W.P. (1980). *Development of predictors of performance under stress in Jumpmaster training* (Research Report No. 1352). Ft. Benning, GA: U.S. Army Research Institute.

Burrows, D. (2002). Memory overload: The effects of amount of information, rate of presentation, and reorganization. *Cognitive Technology, 7*, 20–30.

Bursill, A.E. (1958). The restriction of peripheral vision during exposure to hot and humid conditions. *Quarterly Journal of Experimental Psychology, 10*, 113–129.

Cacioppo, J. T. (1994). Social neuroscience: Autonomic, neuroendocrine, and immune responses to stress. *Psychophysiology, 31*, 113–128.

Cacioppo, J. T., Rourke, P. A., Marshall Goodell, B. S., Tassinary, L. G. (1990). Rudimentary physiological effects of mere observation. *Psychophysiology, 27*(2), 177–186.

Cacioppo, J.T., & Tassinary, L.G. (1990). Inferring psychological significance from physiological signals. *American Psychologist, 45*, 16–28.

Caldwell, J. A. (1997). Fatigue in the aviation environment: an overview of the causes and effects as well as recommended countermeasures. *Aviation, Space, and Environmental Medicine, 68*, 932–938.

Caldwell, J. A. (2001). Efficacy of stimulants for fatigue management: The effects of Provigil (R) and Dexedrine (R) on sleep-deprived aviators. Transportation Research Part F: *Traffic Psychology & Behaviour, 4*, 19–37

Caldwell, J. A., & Caldwell, J.L. (1997). An in-flight investigation of the efficacy of dextroamphetamine for sustaining helicopter pilot performance. *Aviation, Space, and Environmental Medicine, 68*, 1073–1080.

Caldwell, J. A., & Gilreath, S. R (2002). A survey of aircrew fatigue in a sample of U.S. Army aviation personnel. *Aviation, Space, & Environmental Medicine, 73*, 472–480

Callaway, E. (1959). The influence of amobarbital (amylobarbitone) and methamphetamine on the focus of attention. *Journal of Mental Science, 105*, 382–392.

Callaway, E., & Dembo, D. (1958). Narrowed attention: A psychological phenomenon that accompanies a certain physiological change. *Archives of Neurology and Psychiatry, 79*, 74–90.

Callaway, E., & Thompson, S.V. (1953). Sympathetic activity and perception. *Psychosomatic Medicine, 15*, 443–455.

Calvo, M. G., & Castillo, M. D. (2001). Selective interpretation in anxiety: Uncertainty for threatening events. *Cognition and Emotion, 15*, 299–320.

Campbell, R.D., & Austin, S. (2002). Effects of response time deadlines on adult's strategy choices for simple addition. *Memory & Cognition, 30*(6), 988–994.

Campbell, R.D., & Bagshaw, M. (2002). *Human Performance & Limitations in Aviation* (3rd Ed.). London: Blackwell Science.

Cannon, W.B. (1915). *Bodily changes in pain, hunger, fear, and rage*. New York: Appleton.

Cannon-Bowers, J.A., & Salas, E. (1998). *Making decisions under stress*. Washington, D.C.: American Psychological Association.

Cardosi, K.M., & Murphy, E.D. (1995). *Human factors in the design and evaluation of air traffic control systems* (DOT/FAA/RD-95/3). Cambridge, MA: U.S. Department of Transportation, Volpe Research Center.

Carlier, I.V.E., Voerman, A.E., & Gersons, B.P.R. (2000). The influence of occupational debriefing on post-traumatic stress symptomatology in traumatized police officers. British *Journal of Medical Psychology, 73*, 87–98.

Carter, N., & Beh, H. (1989). The effect of intermittent noise on cardiovascular functioning during vigilance task performance. *Psychophysiology, 26*, 548–559.

Carver, C.S., & Scheier, M.F. (1981). *Attention and self-regulation: A control theory approach to human behavior*. New York: Springer Verlag.

Cercarelli, L.R., & Ryan, G.A. (1996). Long distance driving behaviour of Western Australian drivers. In L.R. Hartley (Ed.), *Proceedings of the second international conference on Fatigue and Transportation: Engineering, enforcement and education solutions* (pp. 35–45). Canning Bridge, Australia: Promaco.

Chajut, E., & Algom, D. (2003). Selective attention improves under stress: Implications for theories of social cognition. *Journal of Personality and Social Psychology, 85*(2), 231–248.

Champion, R.A. (1950). Studies of experimentally induced disturbance. *Australian Journal of Psychology, 2*, 90–99.

Christianson, S. (1984). The relationship between induced emotional arousal and amnesia. *Scandinavian Journal of Psychology, 25*, 147–160.

Christianson, S. (1992). Emotional stress and eyewitness memory: A critical review. *Psychological Bulletin, 112*(2), 284–309.

Christianson, S., & Loftus, E.F. (1990). Some characteristics of people's traumatic memories. *Bulletin of the Psychonomic Society, 28,* 195–198.

Christianson, S., & Loftus, E.F. (1991). Remembering emotional events: The fate of detailed information. *Cognition & Emotion, 5*, 81–108.

Christianson, S., Loftus, E.F., Hoffman, H., & Loftus, G.R. (1991). Eye fixations and memory for emotional events. *Jouranl of Experimental Psychology: Learning, Memory, and Cognition, 17,* 693–701.

Clark, R.E. (1961). The limiting hand skin temperature for unaffected manual performance in the cold. *Journal of Applied Psychology, 45*, 193–194.

Coates, G.D., & Alluisi, E.A. (1975). *A review and preliminary evaluation of methodological factors in performance assessments of time-varying aircraft noise effects*. Hampton, VA: National Aeronautics and Space Administration, Langley Research Center.

Cohen, E.L. (1952). The influence of varying degrees of psychological stress on problem-solving rigidity. *Journal of Abnormal and Social Psychology, 47*, 512–519.

Cohen, J.L. (1980). Social facilitation: Audience versus evaluation apprehension effects. *Motivation and Emotion, 4*(1), 21–34.

Cohen, S. (1978). Environmental load and the allocation of attention. In A. Baum, J.E. Singer, & S. Valins (Eds.), *Advances in environmental psychology* (Vol. 1, pp. 1–29). Hillsdale, NJ: Erlbaum.

Cohen, S. (1980). Aftereffects of stress on human performance and social behavior: A review of research and theory. *Psychological Bulletin, 88*, 82–108.

Cohen, S., & Weinstein, N. (1981). Nonauditory effects of noise on behavior and health. *Journal of Social Issues, 37*, 36–70.

Cohen, M.S., & Freeman, J.T., & Thompson, B. (1998). Critical thinking skills in tactical decision making: A model and a training strategy. In J.A. Cannon-Bowers, & E. Salas (Eds.), *Making decisions under stress*. Washington, D.C.: American Psychological Association.

Coleshaw, S.R.K., Van Someren, R.N.M., Wolff, A.H., Davis, H.M., & Keatinge, W.R. (1983). Impaired memory registration and speed of reasoning caused by low body temperature. *Journal of Applied Physiology, 55*, 27–31.

Colquhoun, W.P. (1975). Evaluation of auditory, visual, and dual-mode displays for prolonged sonar monitoring in repeated sessions. *Human Factors, 17*, 425–437.

Combs, A.W., & Taylor, C. (1952). The effect of the perception of mild degrees of threat on performance. *Journal of Abnormal and Social Psychology, 47*, 420–424.

Conlon, L., Fahy, T.J., & Conroy, R. (1999). PTSD in ambulant RTA victims: A randomized controlled trial of debriefing. *Journal of Psychosomatic Research, 46*, 37–44.

Cornum, K.G. (1992). Sustained operations: An F-15 squadron in Gulf War. *Minutes of the Department of Defense Humand Factors Engineering Technical Group 29th Meeting*. Huntsville, AL.

Costa, G. (1993). Evaluation of workload in air traffic controllers. *Ergonomics, 36*, 1111–1120.

Cottrel, N.B. (1972). Social facilitation. In C.G. McClintock (Ed.), *Experimental social psychology* (pp. 185–236). New York: Holt.

Cowan, N. (1999). An embedded-processes model of working memory. Miyake, A., & Shah, P. (Eds.) *Models of working memory*. Cambridge, UK: Cambridge University Press.

Craik, F.I.M, Giovoni, R., Naveh-Benjamin, M., & Anderson, N.D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General, 125*, 159–180.

Crawford, L.E., & Cacioppo, J.T. (2002). Learning where to look for danger: Integrating affective and spatial information. *Psychological Science, 13*(5), 449–453.

Critchley, H.D., & Mathias, C.J. (2003). Blood pressure, attention and cognition: drivers and air traffic controllers. *Clinical Autonomic Research, 13*, 399–401.

D'Amato, M.E., & Gumenik, W.E. (1970). Some effects of immediate versus randomly delayed shock on an instrumental response and cognitive processes. *Journal of Abnormal and Social Psychology, 16*, 1–4.

Dandoy, A.C., & Goldstein, A.G. (1990). The use of cognitive appraisal to reduce stress reactions: A replication. In J.W. Neuliep (Ed.), *Handbook of replication research in the behavioral and social sciences* (pp. 275–285). Select Press.

Davies, D.R., & Parasuraman, R. (1982). *The psychology of vigilance*. London: Academic Press.

Davies, D.R., & Tune, S. (1970). *Human vigilance performance*. London: Staples Press.

Davis, D.R. (1948). *Pilot error*. Air Ministry Publication A.P. 3139A. London: H.M.Stationary Office.

De Jong, G. M., & Emmelkamp, P. M. G. (2000). Implementing a stress management training: Comparative trainer effectiveness. *Journal of Occupational Health Psychology, 5*, 309–320.

Deutsch, J.A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*, 80–90.

Deutsch, S., & Pew, R. (2002). *Modeling human error in a real-world teamwork environment*. Proceedings of the Twenty-fourth Annual Meeting of the Cognitive Science Society (pp. 274–279), Fairfax, VA.

Diamond, D.M, Flechner, M., Ingersoll, N., & Rose, G.M. (1996). Psychological stress impairs spatial working memory: Relevance to electrophsiological studies of hippocampal function. *Behavioral Neuroscience, 110*(4), 661–672.

Diaz, D., Hancock, P.A., & Sims, V.K. (2002). Ecological visual search under noise stress: Present & future research. *23rd Army Science Conference*, Orlando, FL.

Dijksterhuis, A., & Aarts, H. (2003). On wildebeests and humans: The preferential detection of negative stimuli. *Psychological Science, 14*(1), 14–18.

Dimsdale, J.E. (1984). Generalizing from laboratory studies to field studies of human stress physiology. *Psychosomatic Medicine, 46*, 463–469.

Doane, S.M., Woo Sohn, Y., & Jodlowski, M.T. (2004). Pilot ability to anticipate the consequences of flight actions as a function of expertise. *Human Factors, 46*(1), 92–103.

Dorner, D., & Pfeifer, E. (1993). Strategic thinking and stress. *Ergonomics, 36*(11), 1345–1360.

Dougherty, M.R.P. (2001). Integration of the ecological and error models of overconfidence using a multiple-trace memory model. *Journal of Experimental Psychology: General, 130,* 579–599.

Dougherty, M.R.P., Gettys, C.F., & Ogden, E.E. (1999). Minerva-DM: A memory processes model for judgments of likelihood. *Psychological Review, 106*, 180–209.

Dougherty, M.R.P., & Hunter, J. (2003). Probability judgment and subadditivity: The role of working memory capacity and constraining retrieval. *Memory & Cognition, 31*(6), 968–982.

Dowell, S.R., Foyle, D.C., Hooey, B.L., & Williams, J.L. (2002). *The effect of visual location on cognitive tunneling with superimposed HUD symbology*. Paper presented at the 46th Annual meeting of the Human Factors and Ergonomics Society. Santa Monica, CA.

Dreisbach, G., & Goschke, T. (2004). How positive affect modulates cognitive control: Reduced perseveration at the cost of increase distractability. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(2), 343–353.

Drillings, M. & Serfaty, D. (1997). Naturalistic Decision Making in Command and Control. In C.E. Zsambok and G. Klein (Eds.), *Naturalistic Decision Making* (pp. 71–80). Mahwah, NJ: Erlbaum.

Driskell, J.E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology, 79*, 481–492.

Driskell, J. E., & Johnston, J. (1998). Stress exposure training. In J.A. Cannon-Bowers, & E. Salas (Eds.), *Making decisions under stress*. Washington, D.C.: American Psychological Association.

Driskell, J.E., Mullen, B., Johnson, C., Hughes, S., & Batchelor, C. (1992). *Development of quantitative specifications for simulating the stress environment* (Report No. AL-TR-1991-0109). Wright-Patterson AFB, OH: Armstrong Laboratory.

Driskell, J. E., & Salas, E. (1991). Group decision making under stress. *Journal of Applied Psychology, 76*(3), 473–478.

Driskell, J. E., & Salas, E. (1996). *Stress and human performance*. Mahwah, NJ: L. Erlbaum.

Driskell, J. E., Salas, E., & Johnston, J. (1999). Does stress lead to a loss of team perspective? *Group Dynamics: Theory, Research and Practice, 3*(4), 291–302.

Driskell, J. E., Willis, R., & Copper, C. (1992). Effect of overlearning on retention. *Journal of Applied Psychology, 77*, 615–622.

Drucker, E.H., Cannon, L.D., & Ware, J.R. (1969). *The effects of sleep deprivation on performance over a 48-hour period* (HumRRO TR No. 69-8). Alexandria, VA: Human Resources Research Organization.

Duckworth, K.L., Bargh, J.A., Gracia, M., & Chaiken, S. (2002). The automatic evaluation of novel stimuli. *Psychological Science, 13*(6), 513–519.

Duffy, E. (1941). The conceptual categories of psychology: A suggestion for revision. *Psychological Review, 48*, 177–203.

Duffy, E. (1957). The psychological significance of the concept of "arousal" or "activation." *Psychological Review, 64*, 265–275.

Dusek, E.R., (1957). Effect of temperature on manual performance. In F.R. Fisher (Ed.), *Protection and functioning of the hand*. Washington, D.C.: National Academy of Scineces—National Research Council.

Dutke, S., & Stober, J. (2001). Test anxiety, working memory, and cognitive performance. *Cognition & Emotion, 15*, 381–389.

Dyregrov, A., Solomon, R., Bassoe, C.F. (2000). Mental mobilization processes in critical incident stress situations. *International Journal of Emergency Mental Health, 2*(2), 73–81.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66*, 187–201.

Egan, K. (1983). Stress management and child management with abusive parents. *Journal of Clinical Child Psychology, 12*, 292–299

Egbert, L.D., Battit, G.E., Welch, C.E., & Bartlett, M.K. (1964). Reduction of postoperative pain by encouragement and instruction of patients. *New England Journal of Medicine, 270*, 825–827.

Eggemeier, F.T., & Wilson, G.F. (1991). Performance-based and subjective assessment of workload in multi-task environments. In D.L. Damos (Ed.), *Multiple-task performance* (pp. 207–216). London: Taylor & Francis.

Egloff, B., & Hock, M. (2003). Assessing attention allocation toward threat-related stimuli: A comparison of the emotional Stroop task and the attentional probe task. *Personality and Individual Differences, 35*, 475–483.

Eijkam, E., & Vendrik, A.J.H. (1965). Can a sensory system be specific by its internal noise? *Journal of the Accoustical Society of America, 37*, 1102–1109.

Ekman, P. (1977). Biological and cultural contributions to body and facial movement. In J. Blacking (Ed.), *The anthropology of the body* (pp. 39–84). ASA Monograph 15. London: Academic Press

Ellenbogen, M.A., Schwartzman, A.E., Stewart, J., & Walker, C. (2002). Stress and selective attention: The interplay of mood cortisol levels, and emotional information processing. *Psychophysiology, 39*, 723–732.

Ellis, H.D. (1982). The effects of cold on performance of serial choice reaction time and various discrete tasks. *Human Factors, 24*, 589–598.

Ellis, H.D., Wilcock, S.E., & Zaman, S.A. (1985). Cold and performance: The effects of information load, analgesics, and the rate of cooling. *Aviation, Space, and Environmental Medicine, 56*, 233–237.

Enander, A. E. (1989). Effects of thermal stress on human performance. *Scandinavian Journal of Work, Environment & Health, 15*, 27–33

Endler, N. S., Speer, R. L., Johnson, J. M., & Flett, G. L. (2001). General self efficacy and control in relation to anxiety and cognitive performance. *Current Psychology: Developmental, Learning, Personality, Social, 20*, 36–52.

Endsley, M.R. (1995). Toward a theory of situational awareness in dynamic systems. *Human Factors, 37*, 32–64.

Enmonson, D.L., & Vanderbeek, R.D. (1995). The use of dextroamphetamine in support of tactical air operations during Operation Desert Shield/Storm. *Aviation, Space, and Environmental Medicine, 66*, 260–263.

Ennis, M., Kelly, K. S., Wingo, M. K., & Lambert, P. L. (2001). Cognitive appraisal mediates adrenomedullary activation to a psychological stressor. *Stress and Health, 17*, 3–8.

Entin, E. E., & Serfaty, D. (1990). *Information gathering and decision making under stress*. NTIS HC A05/MF A01. Technical Report Number ADA218233; AD-E501191; TR-454

Entin, E.E., & Serfaty, D. (1999). Adaptive team coordination. *Human Factors, 41*(2), 312–325.

Entin, E.E., Serfaty, D., & Deckert, J.C. (1994). *Team adaptation and coordination training*. (TR-648-1). Burlington, MA: ALPHATECH.

Entin, E.E., Serfaty, D., Entin, J.K., & Deckert, J.C. (1993). *CHIPS: Coordination in hierarchical information processing structures*. (TR-598). Burlington, MA: ALPHATECH.

Epstein, Y. (1982). Crowding stress and human behavior. In G.W. Evans (Ed.), *Environmental stress*. New York: Cambridge University Press.

Epstein, S., & Katz, L. (1992). Coping ability, stress, productive load, and symptoms. *Journal of Personality and Social Psychology, 62*(5), 813–825.

Eschenbrenner, A.J. (1971). Effects of intermittent noise on the performance of a complex psychomotor task. *Human Factors, 13*, 59–63.

Eurocontrol. (1997). *PD/1 final report annex A: Experimental design and methods*. (Report PHARE/NATS/PD1-10.2/SSR;1.1). Brussels, Belgium: Author.

Evans, G.W., Hygge, S., & Bullinger, M. (1995). Chronic noise and psychological stress. *Psychological Science, 6*(6), 333–338.

Evans, G.W., & Jacobs, S.V. (1982). Air pollution and human behavior. In G.W. Evans (Ed.), *Environmental stress*. New York: Cambridge University Press.

Evans, G.W., & Johnson, D. (2000). Stress and open-office noise. *Journal of Applied Psychology, 85*(5), 779–783.

Everly, G.S., & Mitchell, J.T. (1999). *Critical incident stress management (CISM): A new era and standard of care in crisis intervention (2nd ed.)*. Ellicott City, MD: Chevron.

Eysenck, M. W. (1979). Anxiety, learning, and memory: A reconceptualization. *Journal of Research in Personality, 13*, 363–385.

Eysenck, M. W. (1985). Anxiety and cognitive task performance. *Personality and Individual Differences, 6*, 579–586.

Eysenck, M. W. (1992). *Anxiety: The cognitive perspective*. Hove, UK: Erlbaum.

Eysenck, M. W. (1997). *Anxiety and Cognition: A unified theory*. Hove, UK: Psychology Press.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6*, 409–434.

Fairclough, S.H. (2001). Mental effort regulation and the functional impairment of the driver. In P.A. Hancock, & P.A. Desmond, *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Fairclough, S.H., & Graham, R. (1999). Impairement of driving performance caused by sleep depreivation or alcohol: A comparative study. *Human Factors, 41*, 118–128.

Falk, J.L., & Bindra, D. (1954). Judgment of time as a function of serial position and stress. *Journal of Experimental Psychology, 47*(4), 279–282.

Farrace, S., Biselli, R., Urbani, L., & Ferlini, .C. (1996). Evaluation of stress induced by flight activity by measuring the hormonal response. *Biofeedback & Self Regulation, 21*, 217–228

Farrace, S., Cenni, P., Tuozzi, G., Casagrande, M., Barbarito, B., & Peri, A. (1999). Endocrine and psychophysiological aspects of human adaptation to the extreme. *Physiology & Behavior. 66*, 613–620

Fazio, R.H., Sanbonmatsu, D.M., Powell, M.C., & Kardes, F.R. (1986). On the automatic activation of attitudes. *Journal of Personality and Social Psychology, 50*, 229–238.

Fendrich, D. W., Healy, A. F., & Bourne, L. E., Jr. (1991). Long-term repetition effects for motoric and perceptual procedures. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 137–151.

Fine, B.J., Cohen, A., & Crist, B. (1960). Effects of exposure to high humidity and moderate ambient temperatures on anagram solution and auditory discrimination. *Psychological Reports, 7*, 171.

Finkelman, J.M., & Glass, D.C. (1970). Reappraisal of the relationship between noise and human performance by means of a subsidiary task measure. *Journal of Applied Psychology, 54*, 211–213.

Finkelman, J.M., Zeitlin, L.R., Romoff, R.A., Friend, M.A., & Brown, L.S. (1979). Conjoint effect of physical stress and noise stress on information processing performance and cardiac response. *Human Factors, 21*, 1–6.

Fisk, A.D., & Schneider, W. (1984). Memory as a function of attention, level of processing, and automatization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 181–197.

Fitts, P. M. (1966). Cognitive aspects of information processing: III. Set for speed versus accuracy. *Journal of Experimental Psychology, 71*(6), 849–857.

Flanagan, J.C. (1954). The critical incident technique. *Psychological Bulletin, 51*, 327–358.

Foa, E.B. (2001). *Guidelines for response to the recent tragic events in the US.* Unpublished manuscript, University of Pennsylvania, Philadelphia.

Fornwalt, N.E. (1965). *Investigating into the effect of intermittent noise of constant periodicity vs. random periodicity on the performance of an industrial task*. Unpublished master's thesis, Texas Tech College (NTIS No. AD-611788).

Foushee, H.C. (1984). Dyads and triads at 35,000 feet: Factors affecting group process and aircrew performance. *American Psychologist, 39*, 885–893.

Foushee, H.C., & Helmreich, R.L. (1988). Group interaction and flight crew performance. In E.L. Wiener, & D.C. Nagel (Eds.), *Human factors in aviation* (pp. 189–227). San Diego: Academic Press.

Fowler, B., Prlic, H., & Brabant, M. (1994). Acute hypoxia fails to influence two aspects of short-term memory: Implications for the source of cognitive deficits. *Aviation, Space, & Environmental Medicine, 65*, 641–645.

Fox, E. (1993). Allocation of visual attention and anxiety. *Cognition and Emotion, 7*, 207–215.

Foyle, D.C., Dowell, S.R., & Hooey, B.L. (2001). *Cognitive tunneling in head-up display (HUD) superimposed symbology: Effects of information location*. In R.S. Jensen, L. Chang, & K. Singleton (Eds.), Proceedings of the Eleventh International Symposium on Aviation Psychology, Columbus, OH: Ohio State University.

Frankenhaeuser, M., Nordheded, B., Myrsten, A.L., & Post, B. (1971). Psychophysiological reaction to understimulation and overstimulation. *Acta Psychologica, 35*, 298–408.

French, B.A. (983). *Some effects of stress on users of a voice recognition system: A preliminary inquiry*. Monterey, CA: Naval Postgraduate School (AD-A128559).

Friedland, N., & Keinan, G. (1992). Training effective performance in stressful situations: Three approaches and implications for combat training. *Military Psychology, 4*, 157–174

Friedland, N., Keinan, G., & Regev, Y. (1992). Controlling the uncontrollability: Effects of stress on illusory perceptions of controllability. *Journal of Personality and Social Psychology, 63*(6), 923–931.

Frijda, N.H. (1986). *The emotions*. Cambridge: Cambridge University Press.

Frijda, N.H. (1996). Passions: Emotion and socially consequent behavior. In R.D. Kavanaugh, B. Zimmerberg, & S. Fein (Eds.), *Emotion: Interdisciplinary perspectives* (pp. 1–27). Mahwah, NJ: Lawrence Erlbaum Associates.

Gaillard, A. W. K. (1993). Comparing the concepts of mental load and stress. *Ergonomics, 36*, 991–1005

Gaillard, A. W. K. (2001). Stress, workload, and fatigue as three biobehavioral states: A general overview. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Gaillard, A. W. K., & Wientjes, C. J. E. (1994). Mental load and work stress as two types of energy mobilization. *Work & Stress, 8*, 141–152

Gal, R., & Mangelsdorff, A.D. (1991). *Handbook of military psychology*. Chicester, NY: Wiley.

Galinsky, T. L., Rosa, R. R., Warm, J. S., & Dember, W.N. (1993). Psychophysical determinants of stress in sustained attention. *Human Factors, 35*, 603–614

Gawron, V.J., French, J., & Funke, D. (2001). An overview of fatigue. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Gaydos, H.F., & Dusek, E.R. (1958). Effects of localized hand cooling versus total body cooling on manual performance. *Journal of Applied Physiology, 12*, 377–380.

Geen, R.G. (1979). Effects of being observed on learning following success and failure experiences. *Motivation and Emotion, 4*, 355–371.

Geer, J.H., Davison, G.C., & Gatchel, R.I. (1970). Reduction of stress in humans through nonveridical perceived control of aversive stimulation. *Journal of Personality and Social Psychology, 16*, 731–738.

Gevins, A., & Smith, M.E. (1999). Detecting transient cognitive impairment with EEG pattern recognition methods. *Aviation, Space, & Environmental Medicine, 70*, 1018–1024.

Giesbrecht, G.G., Arnett, J.L., Psych, C., Vela, E., & Bristow, G.K. (1993). Effect of task complexity on mental performance during immersion hypothermia. *Aviation, Space, and Environmental Medicine*, *64*, 201–211.

Gigerenzer, G., & Selten, R. (2001). *Bounded rationality: The adaptive toolbox*. Cambridge, MA: MIT Press.

Gigerenzer, G., Hoffrage, U., & Kleinbolting, H. (1991). Probabilistic mental models: A Brunswikian theory of confidence. *Psychological Review, 98*, 506–528.

Givoni, R., & Rim, Y. (1962). Effects of the thermal environment and psychological factors upon the subject's responses and performance of mental work. *Ergonomics, 5*, 99–114.

Glass, D.C., & Singer, J.E. (1972). *Urban stress: Experiments on noise and social stressors*. Hew York: Academic Press.

Goff, L.M., & Roediger, H.L. (1998). Imagination inflation for action events: Repeated imaginings lead to illusory recollections. *Memory and Cognition, 26*, 20–33.

Gohm, C.L., Baumann, M.R., & Sniezek, J.A. (2001). Personality in extreme situations: Thinking (or not) under acute stress. *Journal of Research in Personality, 35*, 388–399.

Gomes, L.M.P., Martinho-Pimenta, A.J.F., & Castelo-Branco, N.A.A. (1999). Effects of occupational exposure to low frequency noise on cognition. *Aviation, Space, & Environmental Medicine, 70*, A115–A118.

Gopher, D., Braune, R. (1984). On the psychophysics of workload: Why bother with subjective measures. *Human Factors, 26*(5), 519–532.

Gopher, D., & Donchin, E. (1986). Workload-an examination of the concept. In K.R. Boff, L. Kaufman, & J.P. Thomas (Eds.), *Handbook of perception and human performance* (Vol 2, pp. 41.1–41.49). New York: Wiley.

Gray, J.A. (1990). Brain systems that mediate both emotion and cognition. *Cognition and Emotion, 4*(3), 269–288.

Green, R.G. (1985). Stress and accidents. *Aviation, Space, and Environmental Medicine*, *56*, 638–641.

Greenwood-Ericksen, A., & Ganey, H.C.N. (2002). The effect of time stress on mission performance in a virtual combat mission: Preliminary results.

Grether, W.F. (1973). Human performance at elevated environmental temperature. *Aerospace Medicine, 44*, 747–755.

Gur, R.C., & Reivich, M. (1980). Cognitive task effects on hemispheric blood flow in humans. *Brain & Language, 9*, 78–92.

Haines, M.M., Stansfeld, S.A., Job, R.F.S., Berglund, B., & Head, J. (2001). A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition. *International Journal of Epidemiology, 30*(4), 839.

Hammerton, M., & Tickner, A.H. (1968). An investigation into the effects of stress upon skilled performance. *Ergonomics, 12*, 851–855.

Hammond, K. R. (2000). *Judgments under stress*. New York; Oxford University Press.

Hancock, P. A. (2002, November). *Stress and human performance*. Presentation at the Aberdeen Proving Ground, Maryland.

Hancock, P. A., & Desmond, P. A. (2001) *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Hancock, P.A., Ganey, H.C.N, Mouloua, M., Salas, E., Gilson, R., Greenwood-Ericksen, A., Parasuraman, R., Harris, W., Leon, A., & Smith, K. (2002). *A descriptive framework for the evaluation of stress effects on operator performance*. Paper presented at the 23rd Annual Army Science Conference.

Hancock, P. A., & Ganey, H.C.N. (2002). From the inverted-U to the extended-U: The evolution of a law of psychology. *Journal of Human Performance in Extreme Environments, 7*(1), 5–12.

Hancock, P. A., Ganey, H.C.N., & Szalma, J.L. (2002). *Performance under stress: A re-evaluation of a foundational low of psychology*. Paper presented at the 23rd Annual Army Science Conference.

Hancock, P.A., Meshkati, N., & Robertson, M.M. (1985). Physiological reflections of mental workload. *Aviation, Space, and Environmental Medicine, 56*, 1110–1114.

Hancock, P. A., Szalma, J.L., & Weaver, J.L. (2002). *The distortion of perceptual space-time under stress*. DoD Multidisciplinary Research Program: MURI Operator Performance Under Stress (OPUS), White Paper.

Hancock, P. A., Ward, P., Szalma, J.L., Stafford, S., & Ganey, H.C.N. (2002). *Stress and human information processing: A descriptive framework presented in a novel manner*. Paper presented at the 23rd Annual Army Science Conference.

Hancock, P. A.& Vasmatzidis, I.(1998). Human occupational and performance limits under stress: The thermal environment as a prototypical example. *Ergonomics, 41*, 1169–1191

Hancock, P. A., & Warm, J S. (1989). A dynamic model of stress and sustained attention. *Human Factors, 31*, 519–537.

Hancock, P. A., & Weaver, J.L. (2002). On time distortion under stress. *Theoretical Issues in Ergonomic Science*.

Harris, C.S. (1973). The effects of different types of acoustic stimulation on performance. In W.D. Ward (Ed.), *Proceedings of the International Congress on Noise as a Public Health Problem*. Washington, D.C.: U.S. Environmental Protection Agency.

Harrison, G.A. (1985). Stress, catecholamines, and sleep. *Aviation, Space, and Environmental Medicine, 56*, 651–653.

Hart, S.C., & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock & N.Meshkati (Eds.), *Human mental workload* (pp. 139–183). Amsterdam: North-Holland.

Hartley, L.R. (1981). Noise, attentional selectiviety, serial reactions and the need for experimental power. *British Journal of Psychology, 72*, 101.

Haslam, D.R. (1978). *A comparison of continuous operations upon the military performance of infantrymen: Exercise Early Call II* (APRE Report 4/78). Farnborough, UK: Army Personnel Research Establishment.

Haslam, D.R., & Abraham, P. (1987). Sleep loss and military performance. In G.L. Belenky (Ed.), *Contemporary studies in combat psychiatry* (PP. 167–184). New York: Greenwood Press.

Healy, A. F., & Bourne, L. E., (1995). *Learning and memory of knowledge and skills*. Thousand Oaks, CA: Sage Publications.

Heaps, C.M., & Nash, M. (2001). Comparing recollective experience in true and false autobiographical memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 920–930.

Hebb, D.O. (1955). Drives and the C.N.S. (conceptual nervous system). *Psychological Review, 62*, 243–254.

Helmreich, R.L. (1979). *Social psychology on the flight deck*. Paper presented at the NASA Workshop on Resource Management Training for Airline Flight Crews. San Francisco, CA.

Helmreich, R.L., & Merritt, A.C. (2001). *Culture at work in aviation and medicine: National, organizational and professional influences*. Brookfield: Ashgate.

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education, 21*, 33–46.

Hendy, K.C., Farrell, P.S.E., & East, K.P. (2001). An information-processing model of operator stress and performance. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Hertel, P.T., Mathews, A., Peterson, S., & Kinter, K. (2003). Transfer of training emotionally biased interpretations. *Applied Cognitive Psychology, 17*, 775–784.

Hilburn, B. (1996). *The impact of ATC decision aiding automation on controller workload and human-machine system performance*. (NLR Tech. Pub. TP 96999).

Hilburn, B., & Jorna, P.G.A.M. (2001). Workload and air traffic control. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Hilburn, B., Jorna, P.G.A.M., & Parasuraman, R. (1995). The effect of advanced ATC strategic decision aiding automation on mental workload and monitoring performance: An empirical investigation in simulated Dutch airspace. In *Proceedings of the eighth international symposium on Aviation Psychology*. Columbus: Ohio State University.

Hirst, W., Spelke, E.E., Reaves, C., Caharack, G., & Neisser, U. (1980), Dividing attention without alternation or automaticity, *Journal of Experimental Psychology: General, 109*, 98–117.

Hitch, G.J., & Baddeley, A.D. (1976). Verbal reasoning and working memory. *Quarterly Journal of Experimental Psychology, 28*, 603–621.

Hobbs, M., Mayou, R., Harrison, B., & Worlock, P. (1996). A randomized controlled trial of psychological debriefing for victims of road traffic accidents. *British Medical Journal, 313*, 1438–1439.

Hobfoll, S.E. (1989). Conservation of resources: A new attempt at conceptualizing stress. *American Psychologist, 44*, 513–524.

Hobfoll, S. E. (1991). Traumatic stress: A theory based on rapid loss of resources. *Anxiety Research 4*, 187–197

Hockey, G. R. J. (1970). Effect of loud noise on attentional selectivity. *Quarterly Journal of Experimental Psychology, 22, 28–36*.

Hockey, G. R. J. (1978). Effects of noise on human work efficiency. In D. May (Ed.), *Handbook of noise assessment*. New York: Van Nostrand-Reinhold.

Hockey, G. R. J. (1979). Stress and the cognitive components of skilled performance. (pp. 141–177) In V. Hamilton & D. M. Warburton (Eds.) *Human stress and cognition: An information processing approach*. New York: John Wiley & Sons.

Hockey, G. R. J. (1983). *Stress and human performance*. Chichester, UK: Wiley

Hockey, G.R.J. (1984). Varieties of attentional state: The effects of the environment. In R. Parasuraman & D.R. Davies (eds.), *Varieties of attention* (pp. 449–483). New York: Academic Press.

Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biological Psychology*. *45*, 73–93

Hockey, G. R. J., & Hamilton, P. (1970). Arousal and information selection in short-term memory. *Nature, 226*, 866–867.

Hockey, R., Gaillard, A., & Coles, M. (1986). *Energetics and Human Information Processing*. Dordrecht, Netherlands: Martinus Nijhoff.

Hocking, C., Silberstein, R.B., Lau, W.M., Stough, C., & Roberts, W. (2001). Evaluation of cognitive performance in the heat by functional brain imaging and psychometric testing. *Comparative Biochemistry and Physiology: A Molecular and Integrative Physiology, 128*, 719–734.

Hoffman, R.R., Crandall, B., & Shadbolt, N. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. *Human Factors, 40*(2), 254–276.

Holsti, O.R. (1971). Crises, stress and decision-making. *International Social Science Journal, 23*, 53–67.

Hooijer, J.S., & Hilburn, B.G. (1996). *Evaluation of a label oriented HMI for tactical datalink communication in ATC*. (NLR Tech. Pub. TP 96676 L). Amsterdam: National Aerospace Laboratory NLR.

Horvath, S.M., & Freedman, A. (1957). The influence of cold upon the efficiency of man. *Journal of Aviation Medicine, 18*, 158–164.

Houston, B.K. (1969). Noise, task difficulty, and Stroop color-word performance. *Journal of Experimental Psychology, 82*, 403–404.

Houston, B.K. (1972). Control over stress, locus of control, and response to stress. *Journal of Personality and Social Psychology, 21*, 249–255.

Houston, B.K., & Jones, T.M. (1967). Distraction and Stroop color-word performance. *Journal of Experimental Psychology, 74*, 54–56.

Hovanitz, C.A., Chin, K., & Warm, J.S. (1989). Complexities in life stress-dysfunction relationships: A case in point—tension headache. *Journal of Behavioral Medicine, 12*, 55–75.

Hughes, P.K., & Cole, B.L. (1986). What attracts attention when driving? *Ergonomics, 29*(3), 377–391.

Hull, C.L. (1943). *Principles of behavior*. New York: Appleton-Century.

Humara, M. (2002). The relationship between anxiety and performance: A cognitive-behavioral perspective. *Athletic Insight, 2*, 1–11.

Hutton, R.J.B., Thordsen, M., & Mogford, R. (1997). Recognition primed decision model in air traffic controller error analysis. In R.S. Jensen & L.A. Rakovan (Eds.), *Proceedings of the Ninth International Symposium on Aviation Psychology* (pp. 721–726). Columbus, OH: Ohio State University.

Hyde, D., Thomas, J.R., Schrot, J., & Taylor, W.F. (1997). *Quantification of Special Operations Mission-Related Performance: Operational Evaluation of Physical Measures*. (*Report No. NMRI 97-01*). Bethesda, MD: Naval Medical Research Institute.

Hygge, S., & Knez, I. (2001). Effects of noise, heat, and indoor lighting on cognitive performance and self-reported affect. *Journal of Environment Psychology, 21*, 291–299.

Hyman, I.E., & Pentland, J. (1996). The role of mental imagery in the creation of false childhood memories. *Journal of Memory and Language, 35*, 101–117.

Idzikowski, C., & Baddeley, A.D. (1983). Fear and dangerous environments. In R. Hockey (Ed.), *Stress and Fatigue in Human Performance* (pp. 123–144). Chichester: Wiley.

Ikeda, M., Iwanaga, M. & Seiwa, H. (1996). Test anxiety and working memory system. *Perceptual & Motor Skills, 82*(3), 1223–1231.

Ingledew, D.K., Hardy, L., & Cooper, C.L. (1997). Do resources bolster coping and does coping buffer stress? An organizational study with longitudinal aspect and control for negative affectivity. *Journal of Occupational Health Psychology, 2*(2), 118–133.

Inzana, C. M., Driskell, J. E., Salas, E., & Johnston, J. H. (1996). Effects of preparatory information on enhancing performance under stress. *Journal of Applied Psychology, 81*, 429–435.

Izard, C.E. (1992). Basic emotions, relations among emotions, and emotion-cognition relations. *Psychological Review, 99*(3), 561–565.

Jacoby, L.L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory & Language, 30*(5), 513–541.

James, W. (1890). *The principles of psychology*. New York: Holt.

Janis, I. (1983). The patient as decision maker. In D. Gentry (Ed.), *Handbook of behavioral medicine*. New York: Guilford.

Janis, I., Defares, P., & Grossman, P. (1983). Hypervigilant reactions to threat. In H. Selye (Ed.), *Selye's guide to stress research* (vol. 3, pp. 1–42). New York: Van Nostrand Reinhold.

Janis, I., & Mann, L. (1977). *Decision making*. New York: Free press.

Job, R.F.S., & Dalziel, J. (2001). Defining fatigue as a condition of the organism and distinguishing it from habituation, adaptation, and boredom. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Johnston, N., McDonald, N., & Fuller, R. (1994). *Aviation psychology in practice*. Hants, England: Avebury.

Kagan, N.I., Kagan, H., & Watson, M.G. (1995). Stress reduction in the workplace: The effectiveness of psychoeducational programs. *Journal of Counseling Psychology, 42*(1), 71–78.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliff, NJ: Prentice-Hall.

Kahneman, D. (1975). Effort, recognition and recall in auditory attention. *Attention and Performance, 6*, 65–80.

Kantowitz, B.H., & Campbell, J.L. (1996). Pilot workload and flightdeck automation. In R. Parasuraman & M. Mouloua (Eds.), *Human performance in automated systems* (pp. 117–136). Mahwah, NJ: Lawrence Erlbaum Associates.

Kantowitz, B.H., & Casper, P.A. (1988). Human workload in aviation. In E. Wiener & D. Nagel (Eds.), *Human factors in aviation* (pp. 157–187). New York: Academic Press.

Kantowitz, B.H., & Simsek, O. (2001). Secondary-task measures of driver workload. In P.A. Hancock, & P.A. Desmond, *Stress, workload, and fatigue* (pp. 395–408). Mahwah, NJ: L. Erlbaum.

Karasek, R., Brisson, C., Kawakami, N., Houtman, I., Bongers, P. & Amick, B. (1998). The Job Content Questionnaire (JCQ): An instrument for internationally comparative assessments of psychosocial job characteristics. *Journal of Occupational Health Psychology, 3*, 322–355.

Karasek, R., & Theorell, T. (1990). *Healthy work*. New York: Basic Books.

Kastner, M.P., Entin, E.E., Serfaty, D., Castanon, D.A., & Deckert, J.C. (1989). *Hypothesis testing in a team: A normative-descriptive study*. (Report No. TR-420). Burlington, MA: Alphatech, Inc.

Katz, L, & Epstein, S. (1991). Constructive thinking and coping with laboratory induced stress. *Journal of Personality and Social Psychology, 61*, 789–800.

Keele, S.W. (1973). *Attention and human performance*. Pacific Palisades, CA: Goodyear.

Keinan, G. (1987). Decision making under stress: Scanning of alternatives under controllable and uncontrollable threats. *Journal of Personality and Social Psychology, 52*, 639–644.

Keinan, G. (1988). Training for dangerous task performance: The effects of expectations and feedback. *Journal of Applied Social Psychology, 18*, 355–373.

Keinan, G., & Friedland, N. (1984). Dilemmas concerning the training of individuals for task performance under stress. *Journal of Human Stress, 10*, 185–190.

Keinan, G., Friedland, N., & Sarig-Naor, V. (1990). Training for task performance under stress: The effectiveness of phased training methods. *Journal of Applied Social Psychology. 20*, 1514–1529.

Keinan, G., Friedland, N., Kahneman, D, & Roth, D. (1999). The effect of stress on the suppression of erroneous competing responses. *Anxiety, Stress, & Coping: An International Journal, 12*, 455–476.

Keiss, H.O., & Lockhart, J.M. (1970). Effects of level and rate of body surface cooling on psychomotor performance. *Journal of Applied Psychology, 54*, 386–392.

Kellogg, J. S., Hopko, D. R., & Ashcraft, M. H. (1999). The effects of time pressure on arithmetic performance. *Journal of Anxiety Disorders, 13*, 591–600.

Kensinger, E.A., Clarke, R.J., & Corkin, S. (2003). What neural processes support encoding and retrieval? An fMRI study using a divided attention paradigm. *Journal of Neuroscience, 33*, 2407–2415.

Kensinger, E.A., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vivdly remembered than neutral words? *Memory & Cognition, 31*(8), 1169–1180.

Kerr, B. (1973). Processing demands during mental operations. *Memory and Cognition, 1*, 401–412.

Kiessling, R.J., & Maag, C.H. (1962). Performance impairment as a function of nitrogen narcosis. *Journal of Applied Psychology, 46*, 91–95.

Kimmel, H.D., Van Olst, F.H., & Orlebeke, J.F. (1979). *The orienting reflex in humans*. Hillsdale, NJ: Erlbaum.

Kingstone, A., Smiek, D., Ristic, J., Frieden, C.K., & Eastwood, J.D. (2003). Attention, researchers! It is time to take a look at the real-world. *Current Directions in Psychological Science, 12*(5), 176–180.

Kinsbourne, M., & Hicks, R. (1978). Functional cerebral space. In J. Requin (Ed.), *Attention and performance VII*. Hillsdale, NJ: Erlbaum.

Kirk, R.E., & Hecht, E. (1963). Maintenance of vigilance by programmed noise. *Perceptual and Motor Skills, 16*, 553–560.

Kirschbaum, C., & Hellhammer, D. H. (1994). Salivary cortisol in psychoneuroendocrine research: recent developments and applications. *Psychoneuroendocrinology, 19*, 313–333.

Kirschbaum, C., Wolf, O. T., May, M., Wippich, W. (1996) Stress- and treatment induced elevations of cortisol levels associated with impaired declarative memory in healthy adults. *Life Sciences*. *58*, 1475–1483.

Kivimaki, M., & Lusa, S. (1994). Stress and cognitive performance of fire fighters during smoke-diving. *Stress Medicine, 10*, 63–68.

Kjellberg, A. (1990). Subjective, behavioral, and psychophysiological effects of noise. *Scandinavian Journal of Work, Environment & Health, 16*, 29–38.

Kjellberg, A., Landstroem, U., Tesarz, M., Soederberg, L. (1996). The effects of nonphysical noise characteristics, ongoing task and noise sensitivity on annoyance and distraction due to noise at work. *Journal of Environmental Psychology, 16*, 123–136.

Klein, G.A. (1989). Recognition-primed decision (RPD). In W.B. Rouse (Ed.), *Advances in man-machine systems* (pp. 47–92). Greenwich, CT: JAI.

Klein, G.A., & Klinger, D. (1991). Naturalistic decision-making. *CSERIAC Gateway, 2*, 1–4.

Klein, G.A., Orasanu, J., Calderwood, R., & Zsambok, C.E. (1993). *Decision making in action: Models and methods*. Norwood, NJ: Ablex.

Klein, G.A., & Thordsen, M.L. (1991). Representing cockpit crew decision making. In R.S. Jensen & L.A. Rakovan (Eds.), *Proceedings of the Sixth International Symposium on Aviation Psychology* (pp. 1026–1031). Columbus, OH: Ohio State University.

Kleitman, N. (1963). *Sleep and wakefulness*. Chicago: University of Chicago Press.

Kohn, H. (1954). Effects of variations of intensity of experimentally induced stress situations upon certain aspects of perception and performance. *Journal of Genetic Psychology, 85*, 289–304.

Kornovich, W. (1992). Cockpit stress. *Flying Safety,* 20–23.

Kozlowski, S.W.J. (1998). Training and developing adaptive teams: Theory, principles, and research. In J.A. Cannon-Bowers, & E. Salas (Eds.), *Making decisions under stress*. Washington, D.C.: American Psychological Association.

Kramer, T.H., Buckhout, R., Fox, P., Widman, E., & Tusche, B. (1991). Effects of stress on recall. *Applied Cognitive Psychology, 5*, 483–488.

Krausman, A.S., Crowell, H.P., & Wilson, R.M. (2002). *The effects of physical exertion on cognitive performance* (Report No. ARL-TR-2844). Aberdeen Proving Ground, MD: Army Research Laboratory.

Lampinen, J.M., Odegard, T.N., & Bullington, J.L. (2003). Qualities of memories for performed and imagined actions. *Applied Cognitive Psychology, 17*, 881–893.

Landers, D.M. (1980). The arousal-performance relationship revisited. *Research Quarterly for Exercise and Sport, 51*, 77–90.

Landis, C., & Hunt, W.A. (1939). *The startle pattern*. New York: Farrar and Rinehart.

Landsdown, T.C. (2001). Causes, measures, and effects of driver visual workload. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Laney, C., Heuer, F., Reisberg, D. (2003). Thematically-induced arousal in naturally-occurring emotional memories. *Applied Cognitive Psychology, 17*, 995–1004.

Lang, A J., Craske, M. G., Brown, M, & Ghaneian, A. (2001). Fear-related state dependent memory. *Cognition & Emotion, 15,* 695–703.

Langer, T., Janis, I., & Wolfer, J. (1975). Reduction of psychological stress in surgical patients. *Journal of Experimental Social Psychology, 11*, 155–165.

Larsson, G. (1989). Personality, appraisal, and cognitive coping processes, and performance during various conditions of stress. *Military Psychology, 1*, 167–182.

Lavine, R. A., Sibert, J.L., Gokturk, M., & Dickens, B. (2002). Eye-tracking measures and human performance in a vigilance task. *Aviation, Space, & Environmental Medicine, 73*, 367–372.

Lazarus, R.S. (1966). *Psychological stress and the coping process*. New York: McGraw-Hill.

Lazarus, R. S. (1990). Theory based stress measurement. *Psychological Inquiry, 1*, 3–13.

Lazarus, R. S. (1991). *Emotion and adaptation*. Oxford: Oxford University Press.

Lazarus, R. S. (2000). Toward better research on stress and coping. *American Psychologist, 55*(6), 665–673.

Lazarus, R.S., & Folkman, S. (1984). *Stress, appraisal, and coping*. New York: Springer.

Leavitt, J. (1979). Cognitive demands of skating and stick handling in ice hockey. *Canadian Journal of Applied Sport Sciences, 4*, 46–55.

LeDuc, P. A., Caldwell, J.A., Jr., & Ruyak, P. S. (2000). The effects of exercise as a countermeasure for fatigue in sleep-deprived aviators. *Military Psychology, 12*(4) 249–266.

Lee, L.C. (1961). The effects of anxiety level and shock on a paired-associate verbal task. *Journal of Experimental Psychology, 61*, 213–217.

Lehner, P., Seyed-Solorforough, M., O'Connor, M.F., Sak, S, & Mullin, T. (1997). Cognitive biases and time stress in team decision making. IEEE *Transactions on Systems, Man, & Cybernetics Part A: Systems & Humans, 27*, 698–703.

Leiden, K., Laughery, K.R., Keller, J., French, J., Warwick, W., & Wood, S.D. (2001). *A review of human performance models for the prediction of human error*. NASA system-wide accident prevention program, Ames Research Center.

Leighbody, G., Beck, J., & Amato, T. (1992). An operational evaluation of air traffic controller workload in a simulated en route environment. *37th annual Air Traffic Control Association conference proceedings* (pp. 122–130). Arlington, VA: Air Traffic Control Association.

Leino, T.K., Leppaluoto, J., Ruokonen, A., & Kuronen, P. (1999a). Neuroendocrine responses to psychological workload of instrument flying in student pilots. *Aviation, Space, and Environmental Medicine, 70*(6), 565–570.

Leino, T.K., Leppaluoto, J., Ruokonen, A., & Kuronen, P. (1999b). Neuroendocrine responses to psychological workload of instrument flying in student pilots. *Aviation, Space, and Environmental Medicine, 70*(6), 571–576.

Leplat, J. (1978). The factors affecting workload. *Ergonomics, 21*, 143–149.

Li, G., Baker, S.P., Lamb, M.W., Grabowski, J.G., Rebok, G.W. (2001). Factors associated with pilot error in aviation crashes. *Aviation, Space, & Environmental Medicine, 72*, 52–58.

Libkuman, T.M., Stabler, C.L., Otani, H. (2004). Arousal, valence, and memory for detail. *Memory, 12*(2), 237–247.

Lieberman, H.R., Bathalon, G.P., Falco, C.M, Georgelis, J.H., Morgan, C.A., Niro, P., & Tharion, W.J. (2002). The "fog of war": Documenting cognitive decrements associated with the stress of combat.

Litz, B.T., Gray, M.J., Bryant, R.A., & Adler, A.B. (2002). Early intervention for trauma: Current status and future directions. *Clinical Psychology: Science and Practice, 9*, 112–134.

Loewen, L., & Suedfeld, P. (1992). Cognitive and arousal effects of masking office noise. *Environment and Behavior, 24*, 381–395.

Loftus, E.F. (1980). *Memory*. Reading, MA: Addison-Wesley.

Logie, R.H. (1995). *Visu-spatial working memory*. Hove, Englenad: Erlbaum.

Loomins, C.P. (1960). *Social Systems: Essays on their persistence and change*. New York: Van Nostrand.

Lovallo, W. R. (1997). *Stress and health: Biological and psychological interactions*. Thousand Oaks, CA: Sage.

Lupien, S.J., Gillin, C.J., & Hauger, R.L. (1999). Working memory is more sensitive than declarative memory to the acute effects of corticosteroids: A dose-response study in humans. *Behavioral Neuroscience, 113*(3), 420–430.

Lynn, R. (1966). *Attention, arousal, and the orienting reaction*. London: Pergamon.

MacDonald, R.R., & Labuc, S. (1982). *Parachuting stress and performance* (memorandum 82m511). Farnsborough, England: Army Personnel Research Establishment.

Mack, A. (2003). Inattentional blindness: Looking without seeing. *Current Directions in Psychological Science, 12*(5), 180–184.

MacLeod, C. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*(2), 163–203.

MacLeod, C. (1996). Anxiety and cognitive processes. In I.G. Sarason & G.R. Pierce (Eds.), *Cognitive interference: Theories, methods, and findings* (pp. 47–76). Mahwah, NJ: L. Erlbaum.

MacLeod, C., & Mathews, A. (1988). Anxiety and the allocation of attention to threat. *Quarterly Journal of Experimental Psychology, 40*, 653–670.

MacMillan, J., Paley, M.J., Levchuk, Y.N., Entin, E.E., Freeman, J.T., & Serfaty, D. (2001). *Designing the best team for the task: Optimal organizational structures for military missions*. Santa Monica, CA: Human Factors and Ergonomics Society.

Mackworth, N.H. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology, 1,* 6–21.

Mandler, G. (1979). Thought processes, consciousness, and stress. (pp. 179–201) In V. Hamilton & D. M. Warburton (Eds.) *Human stress and cognition: An information processing approach*. New York: John Wiley & Sons.

Marsh, R.L., Hicks, J.L., & Cook, G.I. (2004). Focused attention on one contextual attribute does not reduce source memory for a different attribute. *Memory, 12*(2), 183–192.

Mathews, K.E., & Canon, L.K. (1975). Environmental noise level as a determinant of helping behavior. *Journal of Personality and Social Psychology, 32*, 571–577.

Mathews, A. & MacLeod, C. (1985). Selective processing of threat cues in anxiety states. *Behaviour Research and Therapy, 23*, 563–569.

Mathews, A. & MacLeod, C. (2002). Induced processing biases have causal effects on anxiety. *Cognition & Emotion, 16*, 331–354.

Matthews, G. (1996). Extraversion, emotion, and performance: A cognitive adaptive model. In G. Matthews (Ed.) *Cognitive science perspectives on personality and emotion*. Amsterdam: Elsevier.

Matthews, G. (2001). Levels of transaction: A cognitive science framework for operator stress. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Matthews, G. (2001). A transactional model of driver stress. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Matthews, G. (2002). Towards a transactional ergonomics for driver stress and fatigue. *Theoretical Issues in Ergonomic Science, 3*, 1–17.

Matthews, G., & Davies, D. R. (1998). *Arousal and vigilance: Still vital at fifty*. Proceedings of the Human Factors and Ergonomics Society, 772–776.

Matthews, G., Davies, D.R., Westerman, S.J., & Stammers, R.B. (2000). *Human performance: Cognition, stress and individual differences*. London: Psychology Press; Philadelphia: Taylor and Francis. ISBN: 0-415-04406-5

Matthews, G., & Desmond, P. A. (1995). Stress as a factor in the design of in-car driving enhancement systems. *Travail Humain, 58*, 109–129.

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*. Mahwah, NJ: L. Erlbaum.

Matthews, G, & Desmond, P. A. (2002). Task-induced fatigue states and simulated driving performance. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 55*, 659–686.

Matthews, G, Sparkes, T. J., & Bygrave, H. M. (1996). Attentional overload, stress, and simulated driving performance. *Human Performance, 9*, 77–101.

Matthews, G., Joyner, L., Gilliland, K., Campbell, S. Falconer, S., & Huggins, J. (1997). Validation of a comprehensive stress state questionnaire: Towards a state "Big Three"? In I. J. F. Mervielde, P. De Fruyt, & F. Ostendorf (Eds.), *Personality Psychology in Europe* (Vol. 7). Tilburg: Tilburg University Press.

May, D.N., & Rice, C.G. (1971). Effects of startle due to pistol shot on control precision performance. *Journal of Sound and Vibration, 15*, 197–202.

Mayou, R.A., Ehlers, A., & Hobbs, M. (2000). Psychological debriefing for road traffic accidents: Three-year follow-up of a randomized controlled trial. *British Journal of Psychiatry, 176*, 589–593.

McBride, D.J. (1988). *An exploration of team information processing in a dynamic group choice task involving uncertainty*. Unpublished Doctoral Dissertation, University of Minnesota.

McCann, C., Baranski, V., Thompson, M. M., & Pigeau, R. A. (2000). On the utility of experiential cross-training for team decision-making under time stress. *Ergonomics, 43*, 1095–1110.

McCarley, J.S., Wickens, C., Goh, J., & Horrey, W.J. (2002). *A computational model of attention/situation awareness*. Paper presented at the 46th Annual meeting of the Human Factors and Ergonomics Society. Santa Monica, CA.

McCarthy, G.W. (1996). G-induced loss of consciousness (GLOC): An aviation psychology challenge. *Journal of Human Performance in Extreme Environments, 1*(2), 42–43.

McCormick, E.J., & Sanders, M.S. (1982). *Human factors in engineering and design*. New York: McGraw-Hill.

McDermott, P., Klein, G., Thordsen, M., Ransom, S., & Paley, M. (2000). *Representing the cognitive demands of new systems: A decision-centered design approach* (Report No. AFRL-HE-WP-TR-2000-0023). Wright-Patterson AFB, OH: Armstrong Laboratory.

McGrath, J.E. (1970). A conceptual formulation for research on stress. In J.E. McGrath (Ed.), S*ocial and psychological factors in stress* (pp. 10–21). New York: Rinehart & Winston.

McGrath, J.E. (1976). Stress and behavior in organizations. In M.D. Dunnette (Ed.), *Handbook of industrial and organizational psychology* (pp. 1351–1395). Chicago: Rand McNally.

McGuinness, D., & Pribram, K.H. (1980). The neuropsychology of attention: Emotional and motivational controls. In M.C. Wittrock (Ed.), *The brain and psychology*. New York: Academic Press.

McKinney, E.H., & Davis, K.J. (2003). Effects of deliberate practice on crisis decision performance. *Human Factors, 45*(3), 436–444.

McLeod, P. (1977). A dual-task response modality effect: Support for multiprocessor models of attention. *Quarterly Journal of Experimental Psychology, 29*, 651–667.

McNally, R.J., Bryant, R.A., & Ehlers, A. (2003). Does early psychological intervention promote recovery from posttraumatic stress? *Psychological Science in the Public Interest, 4*(2), 45–79.

Mears, J.D., & Cleary, P.J. (1980). Anxiety as a factor in underwater performance. *Ergonomics, 23*(6), 549–557.

Meichenbaum, D. (1971). Examination of model characteristics in reducing avoidance behavior. *Journal of Personality and Social Psychology, 17*, 298–307.

Meichenbaum, D. (1985). *Stress inoculation training*. New York: Pergamon.

Metzger, R. L., Miller, M.L., Cohen, M. & Sofka, M. (1990). Worry changes decision making: The effect of negative thoughts on cognitive processing. *Journal of Clinical Psychology, 46*(1), 78–88.

Metzger, U., & Parasuraman, R. (2001). The role of the air traffic controller in future air traffic management: An empirical study of active control versus passive monitoring. *Human Factors, 43*, 519–528.

Miller, G.A., Glanter, E., & Pribram, K.H. (1960). *Plans and the structure of behavior*. New York: Holt, Rinehart & Winston.

Mills, F.J. (1985). The endocrinology of stress. *Aviation, Space, and Environmental Medicine, 56*, 642–650.

Mitchell, J.T. (1983). When disaster strikes…the critical incident stress debriefing process. *Journal of Emergency Medical Services, 8*, 36–39.

Mitchell, J.T., & Everly, G.S. (1995). *Critical incident stress debriefing: An operations manual for the prevention of traumatic stress among emergency services and disaster workers (2nd ed. rev.).* Ellicott City, MD: Chevron.

Mitchell, J.T., & Everly, G.S. (1998). *Critical incident stress management: The basic course workbook (2nd ed.).* Ellicott City, MD: International Critical Incident Stress Foundation.

Miyake, A., & Shah, P. (1999). *Models of working memory*. Cambridge, UK: Cambridge University Press.

Mogford, R.H., Murphy, E.D., & Guttman, J.A. (1993). The use of direct and indirect techniques to study airspace complexity factors in air traffic control. In *Proceedings of the first Mid-Atlantic Human Factors Conference* (pp. 196–202). Norfolk, VA: Old Dominion University.

Mogg, K., Bradley, B. P. & Hallowell, N. (1994). Attentional bias to threat: Roles of trait anxiety, stressful events, and awareness. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 47*, 841–864.

Mogg, T., Mathews, A., & Weinman, J. (1989). Selective processing of threat cues in anxiety states. *Behaviour Research and Therapy, 27*, 317–323.

Mogg, T., Mathews, A., Bird, C., & Macgregor-Morris, R. (1990). Effects of stress and anxiety on the processing of threat stimuli. *Journal of Personality and Social Psychology, 59*(6), 1230–1237.

Monat, A., Averill, J.R., & Lazarus, R.S. (1972). Anticipatory stress and coping reactions under various conditions of uncertainty. *Journal of Personality and Social Psychology, 24*, 237–253.

Moore, J.J., & Massaro, D.W. (1973). Attention and processing capacity in auditory recognition. *Journal of Experimental Psychology, 99*, 49–54.

Moray, N. (1979). *Mental workload: Its theory and measurement*. New York: Plenum.

Morphew, M.E. (2001). The future of human performance and stress research: A new challenge. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Mouloua, M., Deaton, J., & Hitt, J.M. (2001). Automation and workload in aviation systems. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Murata, A. (2004). Foveal task complexity and visual funneling. *Human Factors, 46*(1), 135–141.

Murphy, L.R. (1996). Stress management in work settings: A critical review of the health effects. *American Journal of Health Promotion, 11*, 112–135.

Muscio, B. (1921). Is a test of fatigue possible? *British Journal of Psychology, 12*, 31–46.

NASA. (1996). Fatigue resource directory. In L.R. Hartley (Ed.), *Proceedings of the second international conference on Fatigue and Transportation: Engineering, enforcement and education solutions* (pp. 67–135). Canning Bridge, Australia: Promaco.

Naveh-Benjamin, M., Guez, J., & Marom, M. (2003). The effects of divided attention at encoding on item and associative memory. *Memory & Cognition, 31*(7), 1021–1035.

Navon, D. (1984). Resources: A theoretical soupstone. *Psychological Review, 86*, 254–255.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. *Psychological Review, 86*, 254–255.

Neiss, R. (1988). Reconceptualizing arousal: Psychological states in motor performance. *Psychological Bulletin, 103*, 345–366.

Neisser, U. (1976). *Cognition and reality*. San Francisco: Freeman.

Neisser, U., & Becklan, R. (1975). Selective looking: Attending to visually significant events. *Cognitive Psychology, 7*, 480–494.

Neri, D. F., Oyung, R. L., Colletti, L. M., Mallis, M. M., Tam, P.Y., & Dinges, D. F. (2002). Controlled breaks as a fatigue countermeasure on the flight deck. *Aviation, Space, & Environmental Medicine, 73*, 654–664.

Neuberg, S. L., & Newsom, J. T. (1993). Personal Need for Structure: Individual differences in the desire for simple structure. *Journal of Personality and Social Psychology, 65*, 113–131.

Neufeld, R. W. J. (1999). Dynamic differentials of stress and coping. *Psychological Review, 106*, 385–397.

Newcomer, J.W., Selke, G., Melson, A. K., Hershey, T., Craft, S., Richards, K., & Alderson, A. L. (1999). Decreased memory performance in healthy humans induced by stress-level cortisol treatment. *Archives of General Psychiatry, 56*, 527–533.

Newell, A. (1980). Physical symbol systems. *Cognitive Science, 4*, 135–183.

Newell, B.R., & Shanks, D.R. (2003). Take the best or look at the rest? Factors influencing one-reason decision-making. *Journal of Experimental Psychoogy: Learning, Memory, and Cognition, 29*, 53–65.

Nisbett, R.E., & Wilson, T.D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*, 231–259.

Norman, D.A., & Bobrow, D.J. (1975). On data-limited and resource-limited processes. *Cognitive Psychology, 7*, 44–64.

Norman, D.A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In R.J. Davidson, G.E., Schwarts, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research and theory* (pp. 1–18). New York: Plenum.

Novaco, R. (1975). *Anger control: The development and evaluation of an experimental treatment*. Lexington, MA: D.C. Heath.

Novaco, R. (1977). Stress inoculation: A cognitive therapy for anger and its application to a case of depression. *Journal of Consulting and Clinical Psychology, 45*, 600–608.

Novaco, R. (1980) Training of probation officers for anger problems. *Journal of Counseling Psychology, 27*, 385–390.

Novaco, R., Cook, T., & Sarason, I. (1983). Military recruit training: An arena for stress coping skills. In D. Meichenbaum & M. Jaremko (Eds.), *Stress Reduction and Prevention*. New York: Plenum.

O'Brien, E.J., Cook, A.E., & Peracchi, K.A. (2004). Updating situation models: Reply to Zwaan and Madden (2004). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(1), 289–291.

O'Donnell, R.D., & Eggemeier, F.T. (1986). Workload assessment methodology. In K.R. Boff, L. Kaufman, & J.P. Thomas (Eds.), *Handbook of perception and human performance, Vol. II: Cognitive processes and performance* (pp. 1–49). New York: Wiley Interscience.

Ohman, A. (1993). Fear and anxiety as emotional phenomena: Clinical phenomenology, evolutionary perspectives, and information processing mechanisms. (In M. Lewis & J.M. Haviland (Eds.), *Handbook of emotions*. New York: Guilford.

Ohman, A., Flykt, F.E., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*(3), 466–478.

Ohman, A., Lundquist, D., & Esteves, F. (2001). The face in the crowd revisited: A threat advantage with schematic stimuli. *Journal of Personality and Social Psychology, 80,* 381–396.

Orasanu, J.M. (1990). *Shared mental models and crew decision making* (CSL Report No. 46). Princeton, NJ: Princeton University, Cognitive Science Laboratory.

Osgood, C.E. (1953). *Method and theory in experimental psychology*. New York: Oxford University Press.

Owen, R.S. (1992). Clarifying the simple assumption of the information load paradigm. *Advances in Consumer Research, 19*, 770–776.

Ozel, F. (2001). Time pressure and stress as a factor during emergency egress. *Safety Science, 38*, 95–107.

Palinkas, L. A.; Gunderson, E. K. E.; Johnson, J. C., & Holland, A.W. (2000). Behavior and performance on long-duration spaceflights: Evidence from analogue environments. *Aviation, Space, & Environmental Medicine, 71*, 29–36.

Pamperin, K.L., & Wickens, C.D. (1987). The effects of modality and stress across task type on human performance. *Human Factors Society 31st Annual Meeting*, Human Factors Society, Santa Monica, CA.

Panksepp, J. (1992). A critical role for "affective neuroscience" in resolving what is basic about basic emotions. *Psychological Review, 99*(3), 554–560.

Panksepp, J. (1996). Affective neuroscience: A paradigm to study the animate circuits for human emotions. In R.D. Kavanaugh, B. Zimmerberg, & S. Fein (Eds.), *Emotion: Interdisciplinary perspectives* (pp. 29–60). Mahwah, NJ: Lawrence Erlbaum Associates.

Parasuraman, R., & Hancock, P.A. (2001). Adaptive control of mental workload. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Park, C.L., & Folkman, S. (1997). Meaning in the context of stress and coping. *Review of General Psychology, 1*(2), 115–144.

Paulus, P.B., & Murdoch, P. (1971). Anticipated evalution and audience presence in the enhancement of dominant responses. *Journal of Experimental Social Psychology, 7*, 280–291.

Payne, J.D., Nadel, L., Allen, J.J.B., Thomas, K.G.F., & Jacobs, W.J. (2002). The effects of experimentally induced stress on false recognition. *Memory, 10*(1), 1–6.

Pepler, R.D. (1958). Warmth and performance: An investigation in the tropics. *Ergonomics, 2*, 63–68.

Percival, L., & Loeb, M. (1980). Influence of noise characteristics on behavioral aftereffects. *Human Factors, 22*, 341–352.

Pereira, O., & Jesuino, J. (1987). *Decreasing damaging effects of stress-bound situations: Towards a new model of leadership under stress*. (Technical Report DAJA45-85-C-0036/RN-87-01). Portugal: Universidade Nova De Lisboa.

Plutchik, R., & Ax, A.G. (1967). A critique of determinants of emotional state by Schachter and Singer (1962). *Psychophysiology, 4*, 79–82.

Poulton, E.C. (1978). A new look at the effects of noise: A rejoiner. *Psychological Bulletin, 85*, 1068–1079.

Poulton, E.C. (1979). Composite model for human performance in continuous noise. *Psychological Review, 86*(4), 361–375.

Pribram, K.H., & McGuinness, D. (1975). Arousal, activation, and effort in the control of attention. *Psychological Review, 82,* 116–149.

Pruitt, D.G. (1981). *Negotiation behavior*. New York: Academic Press.

Pruitt, D.G., & Carnevale, P.J.D. (1982). The development of integrative agreements. In V. Derlega and J. Grzelak (Eds.), *Cooperation and helping behavior: Theories and research*. New York: Academic Press.

Pugh, C. R., Nguyen, K. T., Gonyea, J.L., Fleshner, M., Watkins, L.R., Maier, S.F., & Rudy, J.W. (1999). Role of interleukin-1 beta in impairment of contextual fear conditioning caused by social isolation. *Behavioral Brain Research, 106*,109–118.

Pury, C. L. S., & Mineka, S. (2001). Differential encoding of affective and nonaffective content information in trait anxiety. *Cognition & Emotion, 15*, 659–693.

Pylyshyn, Z.W. (1984). *Computation and cognition: Toward a foundation for cognitive science*. Cambridge, MA: MIT Press.

Quick, J. J. (1998). Introduction to the measurement of stress at work. *Journal of Occupational Health Psychology, 3*, 291–293.

Rachman, S.J. (1983). Fear and courage among military bomb-disposal operators [Special Issue]. *Advances in Behaviour Research and Therapy, 4*(3).

Raggatt, P.T. F., & Morrissey, S. A.(1997). A field study of stress and fatigue in long-distance bus drivers. *Behavioral Medicine*. *23*(3), 122–129.

Ramsey, J.D. (1983). Heat and cold. In G.R.J. Hockey (Ed.), *Stress and fatigue in human performance* (pp. 33–60). Chichester: Wiley.

Rapee, Ronald M. (1993). The utilization of working memory by worry. *Behaviour Research & Therapy, 31*(6), 617–620.

Razmjou, S. (1996). Mental workload in heat: Toward a framework for analyses of stress states. *Aviation, Space, & Environmental Medicine, 67*, 530–538.

Razmjou, S., & Kjellberg, A. (1992). Sustained attention and serial responding in heat: Mental effort in the control of performance. *Aviation, Space & Environmental Medicine, 53*, 594–601.

Reason, J. (1990). *Human error*. New York: Cambridge.

Recarte, M.A., & Nunes, L.M. (2000). Effects of verbal and spatial imagery task on eye fixations while driving. *Journal of Experimental Psychology: Applied, 6*, 31–43.

Recarte, M.A., & Nunes, L.M. (2003). Mental workload while driving: Effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology: Applied, 9*(2), 119–137.

Reid, D.D. (1948). Fluctuations in navigator performance during operational sorties. In E.J. Earnaley & P.B. Warr (Eds.), *Aircrew stress in wartime operations*. New York: Academic.

Reid, G., Potter, S., & Bressler, J. (1989). *Subjective Workload Assessment Technique (SWAT): A user's guide*. AAMRL Tech. Rep. AAMRL-TR-89-023). New York: American National Standards Institute.

Renge, K. (1980). The effects of driving experience on a driver's visual attention. An analysis of objects looked at: Using the 'verbal report' method. *International Association of Traffic Safety Sciences Research, 4*, 95–106.

Revelle, W., & Anderson, K.J. (1999). *Personality, motivation and cognitive performance*. (Report No. ARI- Research Note 99-14). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Richards, J. M., Butler, E. A. & Gross, James J. (2003). Emotion regulation in romantic relationships: The cognitive consequences of concealing feelings. *Journal of Social & Personal Relationships, 20*(5), 599–620.

Richards, J.M., & Gross, J.J. (2000). Emotion regulation and memory: The cognitive costs of keeping one's cool. *Journal of Personality & Social Psychology, 79*(3), 410–424.

Rockwell, T.H. (1988). Spare visual capacity in driving—revisited: New empirical results for an old idea. In A.G. Gale, M.H. Freeman, C.M. Hasslegrave, P. Smith, and S.P. Taylor (Eds.), *Vision in vehicles II* (pp. 317–324). Amsterdam: North-Holland.

Rohrbaugh, J.W. (1984). The orienting reflex: Performance and central nervous system manifestations. In R. Parasuraman and D.R. Davies (Eds.), *Varieties of Attention*. New York: Academic Press.

Rohrmann, S., Hennig, J., & Netter, P. (1999). Changing psychobiological stress reactions by manipulating cognitive processes. *International Journal of Psychophysiology, 33*, 149–161.

Rose, S., Bisson, J., Wessely, S. (2001). *Psychological debriefings for preventing post traumatic stress disorder (PTSD)* (Cochrane Library, Issue 3). Oxford, England: Update Software.

Rose, S., Brewin, C.R., Andrews, B., & Kirk, M. (1999). A randomized controlled trial of individual psychological debriefing for victims of violent crime. *Psychological Medicine, 29*, 793–799.

Rosenberg, E., & Caine, Y. (2001). Survey of Israeli Air Force line commander support for fatigue prevention initiatives. *Aviation, Space, & Environmental Medicine, 72*, 352–356.

Rothstein, H.G. (1986). The effects of time pressure on judgment in multiple cue probability learning. *Organizational Behavior and Human Decision Processes, 37*, 83–92.

Rothstein, H.G., & Markowitz, L.M. (1982, May). *The effect of time on a decision stragety*. Paper presented to the meeting of the Midwestern Psychological Association, Minneapolis, MN.

Rotton, J., Olszewski, D. A., Charleton, M. E., & Soler, E. (1978). Loud speech, conglomerate noise, and behavioral aftereffects. Journal of Applied Psychology, **63**, 360–365

Rubin, J.Z., & Brown, B.R. (1975). *The social psychology of bargaining and negotiation*. New York: Academic Press.

Ruffell Smith, H.P. (1979). *A simulator study of the interaction of pilot workload with errors, vigilance, and decisions* (NASA Technical Memorandum 78482). Moffett Field, CA: NASA-Ames Research Center.

Russo, R., Fox, E., Bellinger, L., & Nguyen-Van-Tam, D.P. (2001). Mood congruent free recall in anxiety. *Cognition & Emotion, 15*, 419–433.

Russo, M., Escolas, S., Sing, H., Thorne, D., Johnson, D., Redmond, D., Hall, S., Santiago, S., & Holland, D. (2000). Visual neglect in pilots in a simulated overnight flight. White paper.

Ryan, D.E. (1962). Effects of stress on motor performance and learning. *Research Quarterly, 33*, 111–119.

Sabey, B.E., & Staughton, G.C. (1975). Interacting roles of road environment, vehicle and road user in accidents. In *Proceedings of the fifth international conference of the Association for Accident and Traffic Medicine* (pp. 1–17), London.

Salovey, P. (1992). Mood-induced self-focused attention. *Journal of Personality and Social Psychology, 62,* 699–707.

Salovey P. & Harr, M.D. (1983, April). *Treating writing anxiety: Cognitive restructuring and writing process training*. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Salas, E.M., Driskell, J.E., & Hughes, S. (1996). Introduction: The study of stress and human performance. In J.E. Driskell & E. Salas (Eds.), *Stress and human performance* (pp. 1–46). Hillsdale, NJ: Erlbaum.

Samel, A., Wegmann, H., Vejvoda, M., Drescher, J., Gundel, A., Manzey, D., & Wensel, J. (1997). Two crew operations: Stress and fatigue during long haul flights. *Aviation, Space & Environmental Medicine, 68*, 679–687.

Sandal, G. M., Endresen, I. M., Vaernes, R., & Ursin, H. (1999). Personality and coping strategies during submarine missions. *Military Psychology, 11*, 381–404.

Sanders, A.F. (1983). Towards a model of stress and human performance. *Acta Psychologica, 53*, 61–97.

Sanna, L.J., & Shotland, R.L. (1990). Valence of anticipated evaluation and social facilitation. *Journal of Experimental Social Psychology, 26*, 82–92.

Sarason, I., Johnson, J., Berberich, J., & Siegel, J. (1979). Helping police officers cope with stress: A cognitive-behavioral approach. *American Journal of Community Psychology, 7*, 593–603.

Sauer, J., Hockey, G. R. J., & Wastell, D. G. (1999). Maintenance of complex performance during a 135-dy spaceflight simulation. *Aviation, Space, & Environmental Medicine, 70,* 236–244.

Sauer, J., Hockey, G. R. J., & Wastell, D. G. (1999). Performance evaluation in analogue space environments: Adaptation during an 8-month Antarctic wintering-over expedition. *Aviation, Space, & Environmental Medicine, 70*, 230–235.

Saunders, T., Driskell, J.E., Johnston, J.H., & Salas, E. (1996). The effect of stress inoculation training on anxiety and performance. *Journal of Occupational Health Psychology, 1,* 170–186.

Scerbo, M.W. (2001). Stress, workload, and boredom in vigilance: A problem and an answer. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Schachter, S., & Singer, J.E. (1962). Cognitive, social, and physiological determinants of emotional state. *Psychological Review, 69*, 379–399.

Schaffer, M. (1991). The use of video for analysis of air traffic controller workload. *Journal of Air Traffic Control*, 35–37, 40.

Schellekens, J. M. H., Sijtsma, G. J., Vegter, E., & Meijman, T. F. (2000) Immediate and delayed after-effects of long-lasting mentally demanding work. *Biological Psychology, 53*, 37–56.

Schendel, J.D., & Hagman, J.D. (1982). On sustaining procedural skills over a prolonged retention interval. *Journal of Applied Psychology, 67*, 605–610.

Schmidgall, J. (2001, August). *Frustration and Stress: Implications for Training in Simple Cognitive Tasks*. Unpublished Master's Thesis, University of Colorado.

Schneider, W., & Detweiler, M. (1988). *The role of practice in dual-task performance: Toward workload modeling in a connectionist/control architecture*. Unpublished manuscript.

Schoenberger, R.W., & Harris, C.S. (1965). Human performance as a function of changes in acoustic noise levels. *Journal of Engineering Psychology, 4*, 108–119.

Schupp, H.T., Junhofer, M., Weike, A.I., & Hamm, A.O. (2003). *Psychological Science, 14*(1), 7–13.

Sells, S.B. (1970). On the nature of stress. In J.E. McGrath (Ed.), S*ocial and psychological factors in stress* (pp. 134–139). New York: Rinehart & Winston.

Selye, H. (1956). *The stress of life*. New York: McGraw-Hill.

Senechal, P.K. (1988). Flight surgeon support of combat operations at RAF Upper Heyford. *Aviation, Space, and Environmental Medicine, 59*, 776–777.

Serfaty, D., Entin, E.E., & Johnston, J.H. (1998). Team coordination training. In J.A. Cannon-Bowers, & E. Salas (Eds.), *Making decisions under stress*. Washington, D.C.: American Psychological Association.

Shaffer, L.H. (1975). Multiple attentions in continuous verbal tasks. In P.M.A. Rabitt & S. Dornic (Eds.), *Attention and performance* (pp. 157–167). London: Academic Press.

Shafto, P., & Coley, J.D. (2003). Development of categorization and reasoning in the natural world: Novices to experts, naïve to similarity to ecological knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(4), 641–649.

Sherrod, D.R., & Downs, R. (1974). Environmental determinants of altruism: The effects of stimulus overload and perceived control on helping. *Journal of Experimental Social Psychology, 10*, 468–479.

Shipley, P., & Baranski, J. V. (2002). Police officer performance under stress: A pilot study on the effects of visual-motor behavior rehearsal. *International Journal of Stress Management, 9*, 71–80.

Shostak, B. & Peterson, R.A. (1990). Effects of anxiety sensitivity on emotional response to a stress task. *Behavior Research & Therapy*. *28*, 513–521.

Sinclair, R.C., & Mark, M.M. (1995). The effects of mood state on judgemental accuracy: Processing strategy as a mechanism. *Cognition and Emotion, 9*(5), 417–438.

Singer, R.N, Cauraugh, J.H., Murphey, M., Chen, D., & Lidor, R. (1991). Attentional control, distractors, and motor performance. *Human Performance, 4*, 55–69.

Skinner, N., & Brewer, N. (2002). The dynamics of threat and challenge appraisals prior to stressful achievement events. *Journal of Social and Personality Psychology, 83*, 678–692.

Skosnik, P. D., Chatterton, R. T., Swisher, T., & Park, S. (2000). Modulation of attentional inhibition by norepinephrine and cortisol after psychological stress. *International Journal of Psychophysiology, 36*, 59–68.

Slaven, G. M., & Windle, C. M. (1999). Cognitive performance over 7 days in a distressed submarine. *Aviation, Space, & Environmental Medicine, 70*, 604–608.

Small, R., Lumley, J., Donohue, L., Potter, A., & Waldenstrom, U. (2000). Randomised controlled trial of midwife led debriefing to reduce maternal depression after operative childbirth. *British Medical Journal, 321*, 1043–1047.

Smith, M.D., & Chamberlin, C.J. (1992). Effect of adding cognitively demanding tasks on soccer skill performance. *Perceptual and Motor Skills, 75*, 955–961.

Smith, E.E., & Jonides, J. (1996). Working memory in humans: Neuropsychological evidence. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 1009–1020). Cambridge, MA: MIT Press.

Smock, C.D. (1955). The influence of psychological stress on the intolerance of ambiguity. *Journal of Abnormal Psychology, 50*, 177–188.

Soetens, E., Hueting, J., & Wauters, F. (1992). Traces of fatigue in an attention task. *Bulletin of the Psychonomic Society, 30*, 97–100.

Sokolov, E.N. (1963). Higher nervous functions: The orienting reflex. *Annual Review of Physiology, 25*, 545–580.

Sokolov, E.N. (1975). The neuronal mechanisms of the orienting reflex. In E.N. Sokolov & O.S. Vinogradova (Eds.), *Neuronal mechanisms of the orienting reflex* (pp. 217–235). New York: Wiley.

Speed, A., & Forsythe, J.C. (2002). *Human emulation technology to aid the warfighter: Advances in computational augmentation of human cognition*. White Paper.

Speier, C., Valacich, J.S., & Vessey, I. (1999). The influence of task interruption on individual decision making: An information overload perspective. *Decision Sciences, 30*(2), 337–360.

Spelke, E., Hirst, W., & Neisser, U. (1976), Skills of divided attention, *Cognition, 4*, 215–230.

Spence, K.W. (1951). Theoretical interpretations of learning. In S.S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley.

Spence, J.T., & Spence, D.W. (1966). The motivational components of manifest anxiety: Drive and drive stimuli. In C.D. Spielberger (Ed.), *Anxiety and behavior* (pp. 291–326). New York: Academic Press.

Sperandio, J.C. (1971). Variations of operator's strategies and regulating effects on workload. *Ergonomics, 14*, 571–577.

Spielberger, C. S. (Ed.) (1972). *Anxiety: Current trends in theory and research*. New York: Academic Press.

Staub, E., Tursky, B., & Schwartz, G.E. (1971). Self-control and predictability: Their effects on reactions to aversive stimuli. *Journal of Personality and Social Psychology, 18*, 157–162.

Staw, R.M., Sandelands, L.E., Dutton, J.E. (1981). Threat-rigidity effects in organizational behavior: A multi-level analysis. *Administrative Science Quarterly, 26*, 501–524.

Stein, E.S. (1992). *Air traffic control visual scanning*. (FAA Technical Report DOT/FAA/CT-TN92/16). Washington, DC: U.S. Department of Transportation.

Stemmler, G., Heldmann, M., Pauls, C.A., & Scherer, T. (2001). Constraints for emotion specificity in fear and anger: The context counts. *Psychophysiology, 38*, 275–291.

Sternbach, R.A. (1960). Correlates of difference in time to recover from startle. *Psychosomatic Medicine, 22*, 144–148.

Steyvers, F. J. & Gaillard, A. W (1993). The effects of sleep deprivation and incentives on human performance. *Psychological Research/Psychologische Forschung, 55*, 64–70.

Stokes, A. F. (1995). *Sources of stress-resistant performance in aeronautical decision making: The role of knowledge representation and trait anxiety*. 39th Human Factors and Ergonomics Society Annual Meeting, San Diego, CA, Oct., 1995, Proceedings. Vol. 2 (A96-13001 02-54, p. 887–890

Stokes, A.F., Belger, A., Banich, M.T., & Bernadine, E. (1994). The effects of alcohol and chronic aspartame ingestion upon performance in aviation relevant cognitive tasks. *Aviation, Space, and Environmental Medicine, 65*, 7–15.

Stokes, A.F., Belger, A., & Zhang, K. (1990). *Investigation of factors comprising a model of pilot decision making: Part II. Anxiety and cognitive strategies in expert and novice aviators* (ARL-90-8/SCEEE-90-2). Urbana-Champaign, IL: Institute of Aviation.

Stokes, A.F., Kemper, K.L., & Marsh, R. (1992). *Time-stressed flight decision making: A study of expert and novice aviators* (Technical Report ARL-93-1/INEL-93-1). Urbana-Champaign, IL: Aviation Research Laboratory, University of Illinois.

Stokes, A.F., & Kite, K. (1994). *Flight stress: Stress, fatigue, and performance in aviation.* Burlington, VT: Ashgate.

Stokes, A.F., & Kite, K. (2001). On grasping a nettle and becoming emotional. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Stokes, A. F., Wickens, C., & Kite, K. (1990). *Display technology: Human factors concepts.* Warrendale, PA: Society of Automotive Engineers.

Streufert, S., & Streufert, S.C. (1981). *Stress and information search in complex decision making: Effects of load and time urgency* (Technical Report No. 4). Arlington, VA: Office of Naval Research.

Sullivan, L. (1976). Selective attention and secondary message analysis: A reconsideration of Broadbent's filter model of selective attention. *Quarterly Journal of Experimental Psychology, 28*, 167–178.

Sullivan, S. E., & Bhagat, R. S. (1992). Organizational stress, job satisfaction and job performance: Where do we go from here? *Journal of Management, 18*(2), 353–374.

Suzuki, T., Nakamura, Y., & Ogasawara, T. (1966). Intrinsic properties of driver attentiveness. *The Expressway and the Automobile, 9,* 24–29.

Szalma, J.L., & Hancock, P.A. (2002). *On mental resources and performance under stress*. U.S. Army Research Office, MURI-OPUS. White Paper.

Szpiler, J.A., & Epstein, S. (1976). Availability of an avoidance response as related to autonomic arousal. *Journal of Abnormal Psychology, 85*, 73–82.

Taynor, J., Crandell, B., & Wiggins, S. (1987). *The reliability of the critical decision method* (Technical Report Contract MDA903-86-C-0170, U.S. Army Research Institute). Fairborn, OH: Klein Associates, Inc.

Teichner, W.H., Areas, E., & Reilly, R. (1963). Noise and human performance: A psychological approach. *Ergonomics, 6*, 83–97.

Temple, J. G., Warm, J. S., Dember, W. N, Jones, K. S., LaGrange, C. M., & Matthews, G. (2000) The effects of signal salience and caffeine on performance, workload, and stress in an abbreviated vigilance task. *Human Factors, 42*, 183–194.

Tepas, D.I., & Price, J.M. (2001). What is stress and what is fatigue?. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Thackray, R.I. (1965). Correlates of reaction time to startle. *Human Factors, 7*, 74–80.

Thackray, R.I. (1988). *Rate of initial recovery and subsequent radar monitoring performance following a simulated emergency involving startle*. FAA Office of Aviation Medicine Report No. FAA-AM-83-13.

Thackray, R.I., & Touchstone, R.M. (1983). *Performance recovery following startle: A laboratory approach to the study of behavioral response to sudden aircraft emergencies*. FAA Office of Aviation Medicine Report No. FAA-AM-88-4.

Theologus, G.C., Wheaton, G.R., & Fleishman, E.A. (1974). Effects of intermittent, moderate intensity noise stress on human performance. *Journal of Applied Psychology, 59*, 539–547.

Theorell, T. & Karasek, R. (1996). Current issues relating to psychosocial job strain and cardiovascular disease research. *Journal of Occupational Health Psychology, 1*, 9–26.

Thompson, S.C. (1981). Will it hurt less if I can control it? A complex answer to a simple question. *Psychological Bulletin, 90*, 89–101.

Thompson, L. A., Williams, K. L., L'Esperance, P. R., & Cornelius, J. (2001). Context dependent memory under stressful conditions: The case of skydiving. *Human Factors, 43*, 611–619.

Tohill, J. M., & Holyoak, K. J. (2000) The impact of anxiety on analogical reasoning. *Thinking & Reasoning, 6*, 27–40.

Townsend, J.T., & Ashby, F.G. (1980). *The stochastic modeling of elementary psychological processes*. Cambridge: Cambridge University Press.

Treisman, A.M. (1969). Strategies and models of selective attention. *Psychological Review, 76*, 282–299.

Treisman, A.M. (1988). Features and objects: The fourteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimeintal Psychology, 40A*, 201–237.

Treisman, A.M., & Davies, A. (1973). Divided attention to ear and eye. In S. Kornblum (Ed.), *Attention and performance: Volume IV* (pp. 101–117). London: Academic Press.

Tulving, E., & Lindsay, P.H. (1967). Identification of simultaneously presented simple visual and auditory stimuli. In A.F. Sanders (Ed.), *Attention and performance: Vol. I.* Amsterdam: North-Holland.

Turk, D., Meichenbaum, D., & Genest, M. (1983). *Pain and behavioral medicine*. New York: Guilford.

Turner, T.J., & Ortony, A. (1992). Basic emotions: can conflicting criteria converge? *Psychological Review, 99*(3), 566–571.

Tversky, A., & Koehler, D.J. (1994). Support theory: A nonextensional representation of subjective probability. *Psychological Review, 101*, 547–567.

Uhlarik, J., & Comerford, D.A. (2002). *A review of situation awareness literature relevant to pilot surveillance functions* (Report No. DOT/FAA/AM-02/3). Office of Aerospace Medicine, Washington, D.C.: Federal Aviation Administration.

Van Dongen, H.P.A., Maislin, G., Mullington, J.M., & Dinges, D.F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep, 26*(2), 117–126.

Van Emmerik, A.A.P., Kamphuis, J.H., Hulsbosch, A.M., & Emmelkamp, P.M.G. (2002). Single session debriefing after psychological trauma: A meta-analysis. *Lancet, 360*, 766–771.

Van Galen, G. P. & van Huygevoort, M. (2000). Error, stress and the role of neuromotor noise in space oriented behaviour. *Biological Psychology, 51*, 151–171.

Van Gemmert, A. W. A., & Van Galen, G. P. (1997). Stress, neuromotor noise, and human performance: A theoretical perspective. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 1299–1313.

Van Olst, E.H. (1971). *The orienting reflex*. The Hague: Mouton.

Van Overschelde, J.P., & Healy, A.F. (2001). Learning of nondomain facts in high- and low-knowledge domains. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 1160–1171.

Vasmatzidis**,** I., Schlegel, R. E., & Hancock, P. A. (2002). An investigation of heat stress effects on time-sharing performance. *Ergonomics*. *45*(3), 218–239.

Vasterling, J.J., Brailey, K., Constans, J.I., & Sutker, P.B. (1998). Attention and memory dysfunction in posttraumatic stress disorder. *Neuropsychology, 12*(1), 125–133.

Vaughan, J.A., Higgins, E.A., & Funkhouser, G.E. (1968). Effects of body thermal state on manual performance. *Aerospace Medicine, 39*, 1310–1315.

Vaughan, W.S. (1977). Distraction effect of cold water on performance of higher-order tasks. *Undersea Biomedical Research, 4*, 103–116.

Vedhara, K., Hyde, J., Gilchrist, I. D., Tytherleigh, M., & Plummer, S. (2000) Acute stress, memory, attention, and cortisol. *Psychoneuroimmunology, 25*, 535–549.

Ververs, P. M., & Wickens, C. D. (1998). Head-up displays: Effects of clutter, display intensity, and display location on pilot performance. *The International Journal of Aviation Psychology, 8*(4), 377–403.

Villoldo, A., & Tarno, R.L. (1984). *Measuring the performance of EOD equipment and operators under stress* (Technical Rep. No. 270). Indian Head, MD: Naval Explosive Ordinance Disposal Technical Center.

Von Wright, J., & Vauras, M. (1980). Interactive effects of noise and neuroticism on recall from semantic memory. *Scandinavian Journal of Psychology, 21*, 97–101.

Vroom,V. (1964). *Work and motivation*, New York: Wiley.

Wall, J.G. (1992). Vehicle safety—what are the needs? In *XXIV FISITA Congress Technical Papers: Safety, the vehicle & the road: Part 1*. C389/470: 925201. I. Mech. E. (pp. 9–19), London.

Walton, R.E., & McKersie, R.B. (1965). *A behavioral theory of labor negotiation: An analysis of a social interaction system*. New York: McGraw-Hill.

Walters, B.A., Huber, S., French, J., Barnes, M.J. (2002). *Using simulation models to analyze the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles* (Report No. ARL-CR-0483). Aberdeen Proving Ground, MD: Army Research Laboratory.

Walters, J.M, & Sumwalt, R.L. (2000). *Aircraft accident analysis*. New York: McGraw-Hill.

Weaver, J.L., Bowers, C.A., & Salas, E. (2001). Stress and teams: Performance effects and interventions. In P.A. Hancock, & P.A. Desmond (Eds.), *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Wee, D.F., Mills, D.M., & Koehler, G. (1999). The effects of critical incident stress debriefing (CISD) on emergency medical services personnel following the Los Angeles civil disturbance. *International Journal of Emergency Mental Health, 1,* 33–37.

Weinberg, J., & Levine, S. (1980). Psychobiology of coping in animals: The effects of predictability. In S. Levine & H. Ursin (Eds.), *Coping and health* (NATO Conference Series III: Human factors). New York: Plenum.

Weinstein, N.D. (1974). Effect of noise on intellectual performance. *Journal of Applied Psychology, 59*, 548–584.

Weisman, A., Worden, J., & Sobel, H. (1980). *Psychosocial screening and intervention with cancer patients*. Unpublished manuscript. Harvard Medical School.

Welford, A.T. (1973). Stress and performance. *Ergonomics, 15*, 567–580.

Wessel, I., & Merckelbach, H. (1994). Charateristics of traumatic memories in normal subjects. *Behavioral & Cognitive Psychotherapy, 22*, 315–324.

Westman, M. (1996). Implicit stress theory: An experimental examination of the impact of rater's stress on performance appraisal. *Journal of Social Behavior and Personality, 11*(4), 753–766.

Westman, M., & Eden, D. (1996). The inverted-U relationship between stress and performance: A field study. *Work & Stress, 10*(2), 165–173.

Whittaker, R.A. (1995). *Computer assistance for en-route (CAER) trials programme: Future system 1 summary report*. (CS Rep. 9529). London: Civil Aviation Authority National Air Traffic Services.

Wiener, E.L., & Nagel, D.C. (1988). *Human factors in aviation*. San Diego: Academic Press.

Wiener, E.L., Kanki, B.G., & Helmreich, R.L. (1993). *Cockpit Resource Management*. San Diego: Academic Press.

Wickens, C.D. (1980). The structure of attentional resources. In R. Nickerson (Ed.), *Attention and performance: Vol. VIII*. Hillsdale, NJ: Erlbaum.

Wickens, C.D. (1984). Processing resources in attention. In R. Parasuraman & D.R. Davies (Eds.), *Varieties of attention* (pp. 63–101). New York: Academic Press.

Wickens, C.D. (1991). Processing resources and attention. In D.L. Damos (Ed.), *Multiple-task performance* (pp. 3–34). Washington D.C.: Taylor & Francis.

Wickens, C.D. (1992). *Engineering psychology and human performance 2nd Edition*. New York: Harper-Collins.

Wickens, C. D. (2002). Situation awareness and workload in aviation. *Current Directions in Psychological Science, 11*, 128–133.

Wickens, C. D., & Dixon, S.R. (2002). Pilot control of multiple-UAVs: Predicting performance through operator workload and task interference models.

Wickens, C.D., Fadden, S., Merwin, D., & Ververs, P.M. (1998). Cognitive factors in aviation display design. *Proceedings of the 17th Digital Avionics Systems Conference*, Institutes of Electrical & Electronic Engineers.

Wickens, C.D., Stokes, A., Barnett, B., & Hyman, F. (1991). The effects of stress on pilot judgment in a MIDIS simulator. In O. Svenson and A.J. Maule (Eds.), *Time Pressure and Stress in Human Judgment and Decision Making* (pp. 271–292). New York: Plenum Press.

Wiggins, M. & O'Hare, D. (1995). Expertise in aeronautical weather-related decision making: A cross-sectional analysis of general aviation pilots. *Journal of Experimental Psychology: Applied, 1*(4), 305–320.

Wilkinson, R.T. (1964). Effects of up to 60 hours' sleep deprivation on different types of work. *Ergonomics, 7*, 175–186.

Williams, H.L., Lubin, A., & Goodnow, J.J. (1959). Impaired performance with acute sleep loss. *Psychological Monographs, 73*(14), 1–26.

Williams, J.M., Tonymon, P., & Anderson, M.B. (1990). Effects of life-event stress on anxiety and peripheral narrowing. *Behavioral Medicine*, 174–184.

Williams, J.M.G., Watts, F.N., MacLeod, C., & Mathews, A. (1988). *Cognitive psychology and emotional disorders*. Chichester: John Wiley.

Wilson, J.R., Hooey, B.L., Foyle, D.C., & Williams, J.L. (2002). *Comparing pilots' taxi performance, situation awareness and workload using command-guidance, situation-guidance and hybrid* *head-up display symbologies*. Paper presented at the 46th Annual meeting of the Human Factors and Ergonomics Society. Santa Monica, CA.

Wilson, G., Skelly, J., & Purvis, B. (1989, October). Reactions to emergency situations in actual and simulated flight. In *Proceedings of the Aerospace Medical Panel Symposium*, 1-13. The Hague, Netherlands.

Windschitl, P.D., & Wells, G.L. (1998). The alternative-outcomes effect. *Journal of Personality & Social Psychology, 75*, 1441–1423.

Wofford, J. C. (2001). Cognitive-affective stress response effects of individual stress propensity on physiological and psychological indicators of strain. *Psychological Reports, 88*, 768–784.

Wofford, J. C., & Daly, P. S. (1997). A Cognitive-affective approach to understanding individual differences in stress propensity and resultant strain. *Journal of Occupational Health Psychology, 2*(2), 134–147.

Wofford, J. C., & Goodwin, V. L. (2002). The linkages of cognitive processes, stress propensity, affect, and strain: Experimental test of a cognitive model of stress response. *Personality & Individual Differences, 32*, 1413–1430.

Wofford, J. C., Goodwin, V. L., & Daly, P. S. (1999). Cognitive-affective stress propensity: A field study. *Journal of Organizational Behavior, 20*, 687–707.

Wood, J., Mathews, A., & Dalgleish, T. (2001). Anxiety and cognitive inhibition. *Emotion, 1*, 165–181.

Woods, D.D., & Patterson, E.S. (2001). How unexpected events produce an escalation of cognitive and coordinative demands. In P.A. Hancock, & P.A. Desmond, *Stress, workload, and fatigue*. Mahwah, NJ: L. Erlbaum.

Worchel, S., & Yohai, S.M.L. (1979). The role of attribution in the experience of crowding. *Journal of Experimental Social Psychology, 15*, 91–104.

Wright, P. (1974). The harassed decision maker: Time pressures, distractions, and the use of evidence. *Journal of Applied Psychology, 59*, 555–561.

Yamamoto, T. (1984). Human problem solving in a maze using computer graphics under an imaginary condition of "fire." *Japanese Journal of Psychology, 55*, 43–47.

Yeo, G.B., & Neal, A. (2004). A multilevel analysis of effort, practice, and performance: Effects of ability, conscientiousness, and goal orientation. *Journal of Applied Psychology, 89*(2), 231–247.

Yerkes, R.M., & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-information. *Journal of Comparative Neurology of Psychology, 18*, 459–482.

Zajonc, R.B. (1965). Social facilitation. *Science, 149*, 269–274.

Zajonc, R.B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist, 35*, 151–175.

Zakay, D., & Wooler, S. (1984). Time pressure, training and decision effectiveness. *Ergonomics, 27*, 273–284.

Zakowski, S., Hall, M. H., & Baum, A. (1992) Stress, stress management, and the immune system. *Applied & Preventive Psychology, 1*, 1–13

Zakowski, S. G., Hall, M. H., Cousino-Klein, H., & Baum, A. (2001) Appraised control, coping, and stress in a community sample: A test of the goodness-of-fit hypothesis. *Annals of Behavioral Medicine, 23*, 158–165

Zeier, H. (1994). Workload and psychophysiological stress reactions in air traffic controllers. *Ergonomics, 37*, 525–539.

Zhang, K. (1989). *Effects of noise and workload on performance with object displays versus separated displays*. Unpublished doctoral dissertation, University of Illinois.

Zohar, D., & Brandt, Y. (2002). Relationships between appraisal factors during stressful encounters: A test of alternative models. *Anxiety, Stress, & Coping: An International Journal, 15*, 149–161.

Zwaan, R.A., & Madden, C.J. (2004). Updating situation models. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(1), 283–288.

Author's Note

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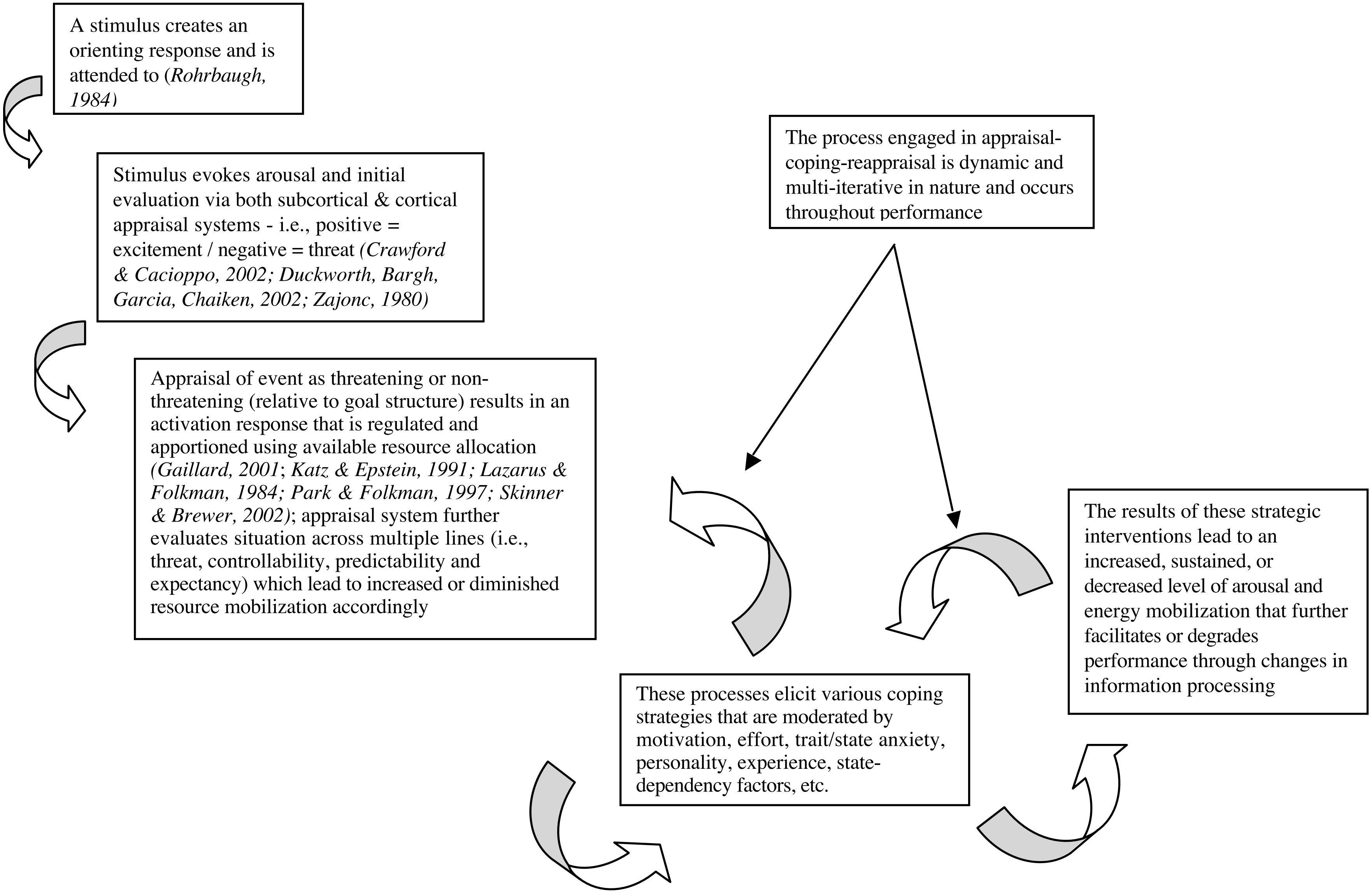
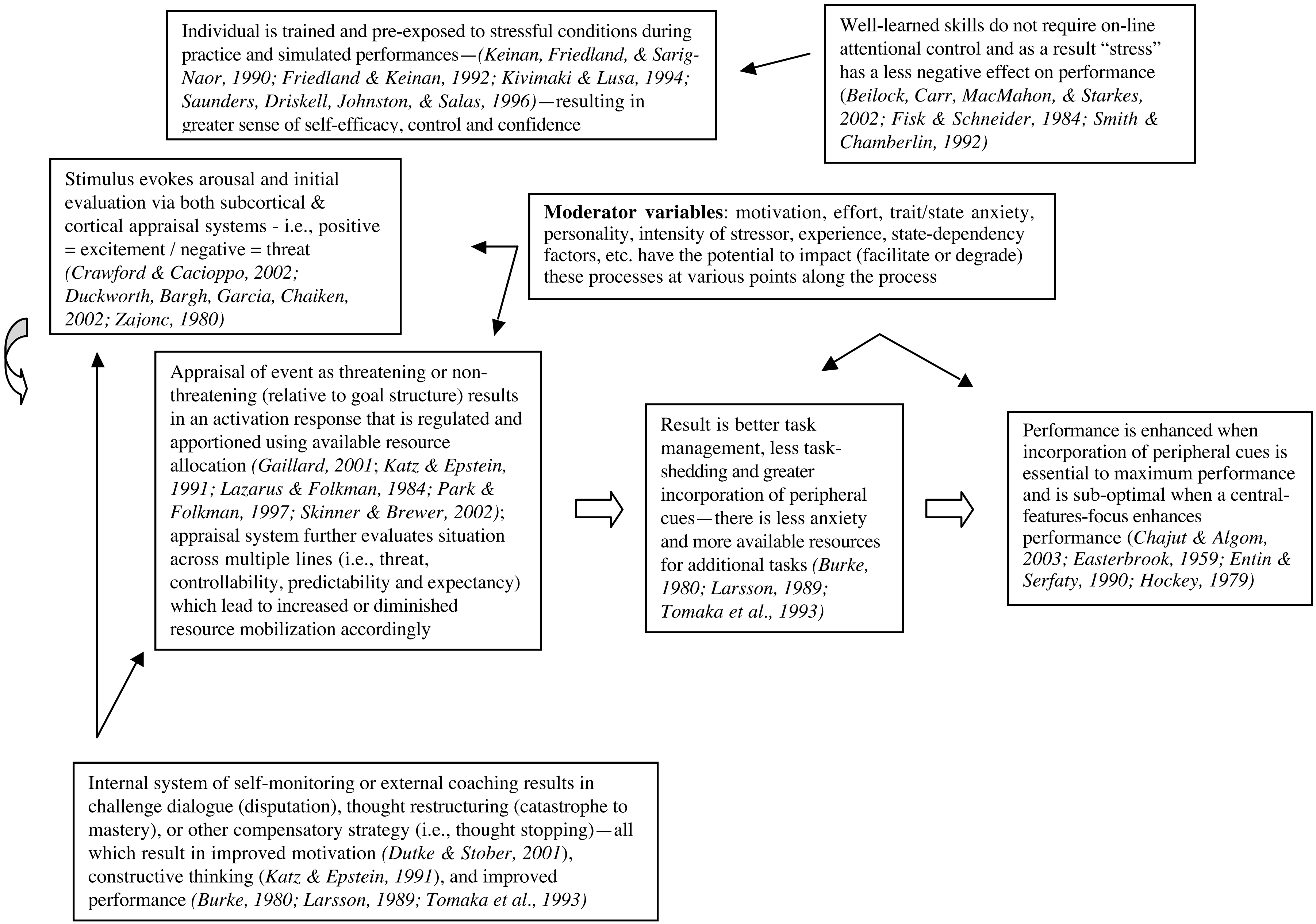
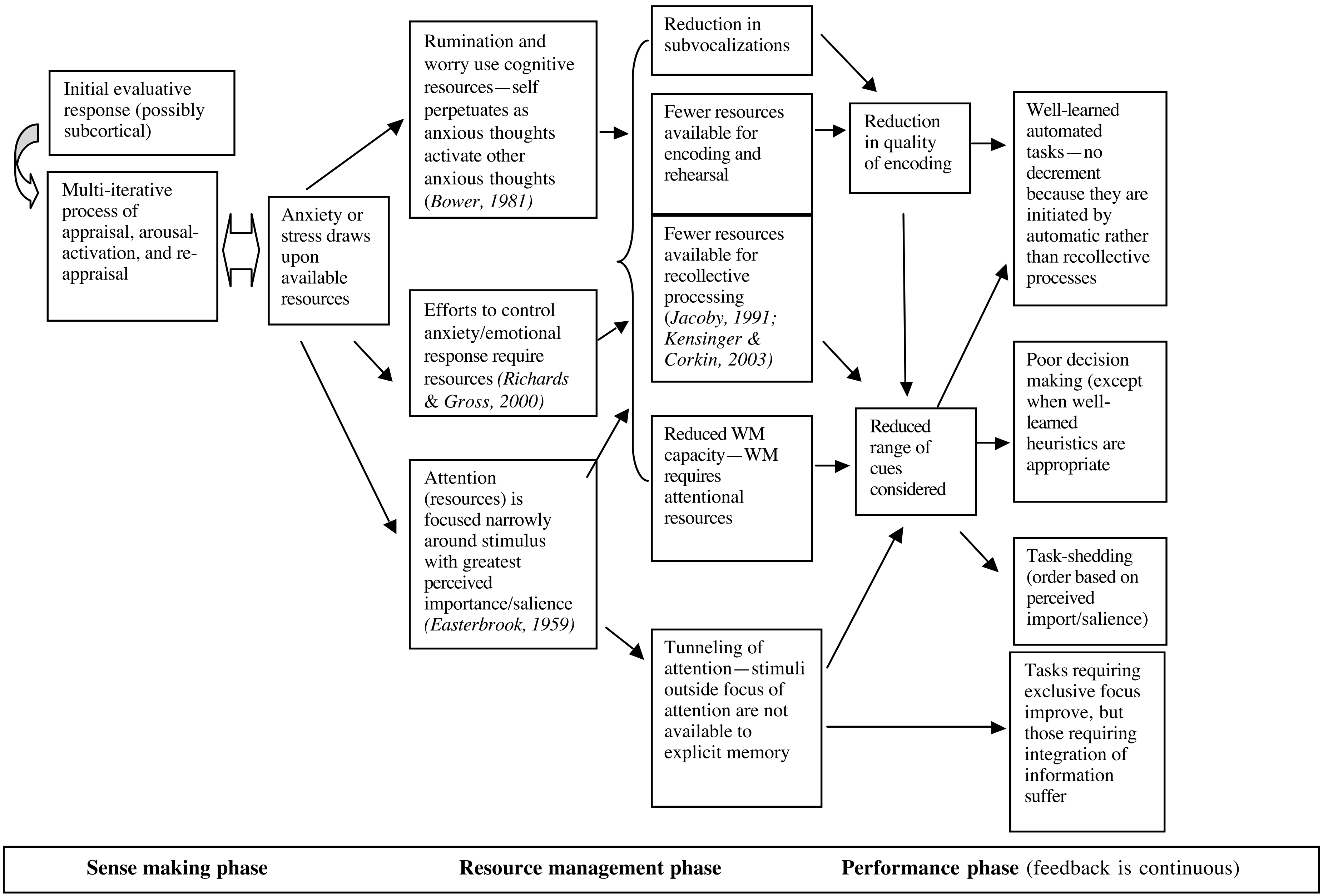
Appendix A: Cognitive Appraisal Processing Elements



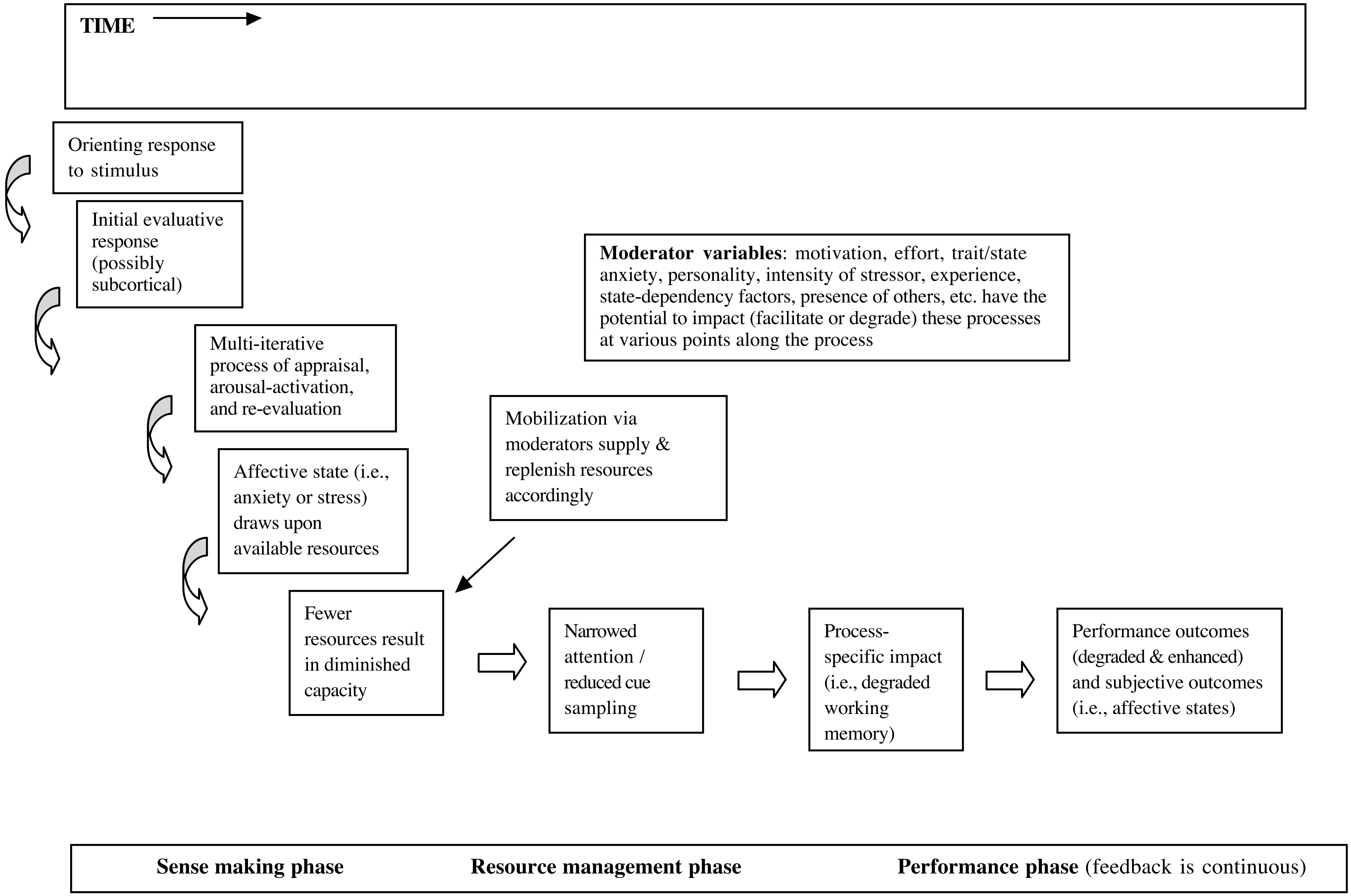
Appendix B: Cognitive Stress Intervention Model (Restructuring and Inoculation)



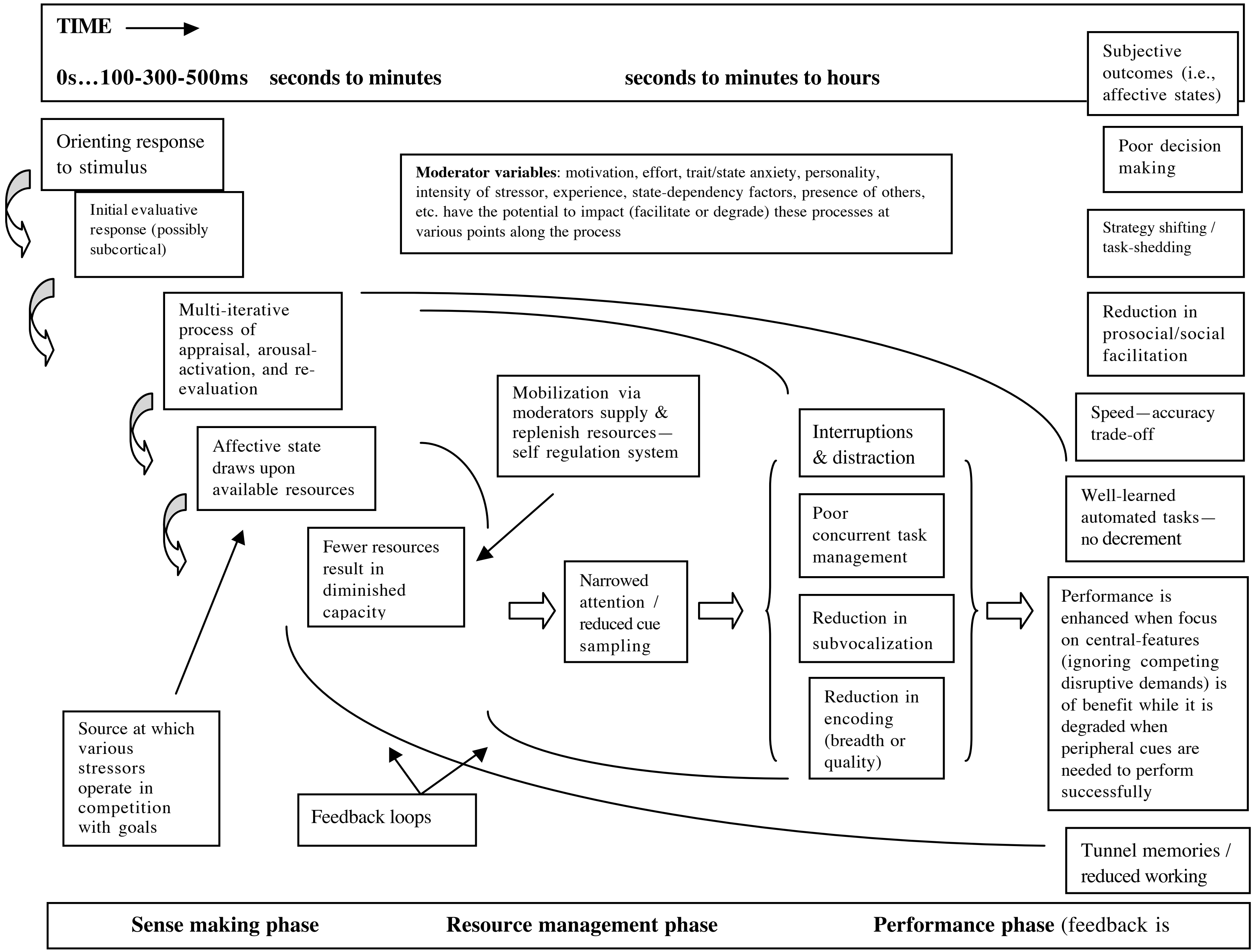
Appendix C: Attentional and Memory Processing under Stress



Appendix D: Stress Effects on Information Processing (brief outline)



Appendix E: Stress Effects on Information Processing (expanded outline)



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13. ABSTRACT *(Maximum 200 words)*

The following literature review addresses the effects of various stressors on cognition. While attempting to be as inclusive as possible, the review focuses its examination on the relationships between cognitive appraisal, attention, memory, and stress as they relate to information processing and human performance. The review begins with an overview of constructs and theoretical perspectives followed by an examination of effects across attention, memory, perceptual-motor functions, judgment and decision making, putative stressors such as workload, thermals, noise, and fatigue and closes with a discussion of moderating variables and related topics. In summation of the review, a conceptual framework for cognitive process under stress has been assembled. As one might imagine, the research literature that addresses stress, theories governing its effects on human performance, and experimental evidence that supports these notions is large and diverse. In attempting to organize and synthesize this body of work, I was guided by several earlier efforts (Bourne & Yaroush, 2003; Driskell, Mullen, Johnson, Hughes, & Batchelor, 1992; Driskell & Salas, 1996; Handcock & Desmond, 2001; Stokes & Kite, 1994). These authors should be credited with accomplishing the monumental task of providing focused reviews in this area and their collective efforts laid the foundation for this present review. Similarly, the format of this review has been designed in accordance with these previous exemplars. However, each of these previous efforts either simply reported general findings, without sufficient experimental illustration, or narrowed their scope of investigation to the extent that the breadth of such findings remained hidden from the reader. Moreover, none of these examinations yielded an architecture that adequately describes or explains the inter-relations between information processing elements under stress conditions. It is the author's hope that this review may provide an initial step toward this end.

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