Stress and Cognition: A Cognitive Psychological Perspective

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Outline

Stress and Cognition: A Cognitive Psychological Perspective

Introduction
Cognition in Emergency and other Abnormal Situations
Acute and Chronic Stress
Teamwork under Emergencies

The Purpose of this Review
Preliminary Guidelines from Cognitive Psychology
An Example
Research Methods

Measures of Stress Effects
Neuro-physiological Measures of Stress
Self- report Measures
Performance or Behavioral Measures
Conclusions

Definitions of Stress

Theories of Stress and Cognition
Conclusions

Arousal and Performance.
Motivation and Arousal
Stress and Arousal
Stress States: Qualitative Effects of Stress
Conclusions

Appraisal

Conclusions

Attention and Perception

Inhibition and Attention
Perception and Cue Utilization
Vigilance
Conclusions

Memory

General Stress Effects on Memory.
Cortisol and other Neuro-biological Considerations..
Context And State Dependency involving Stress.
Other Considerations
A Memory Constriction Hypothesis
Conclusions

Environmental Conditions that Induce Stress

Time Pressure
Work Load and Overload
Fatigue and Sleep Deprivation
Noise
Ambient Temperature
Miscellaneous Stress Variables: Extreme Environments
Conclusions

Individual Differences Variables

Trait Anxiety and Stress
Other Personality Variables
Health and Coping Styles
Conclusions

Stress Countermeasures

Task Conditions

Stress Management

Conclusions

Other Reviews of the Literature

Summary and Conclusions

References

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Complex operations can be performed successfully in Space by human beings, but more slowly than doing the same tasks on Earth (Fowler, Comfort & Bock, 2000; Watt, 1997)), Fowler, et al. (2000) and Manzey (2000) propose two hypotheses to account for this performance degradation—(1) the direct effects of microgravity on the central nervous system and the motor system of the body and (2) the non-specific effects of multiple stressors. Evidence available to date is consistent with both hypotheses and further experiments are required to settle this question. The issue has practical implications because the countermeasures needed to ameliorate or prevent performance deficits will differ according to which hypothesis is correct. Understanding and ameliorating performance deficits will surely help ensure safer operations aboard the International Space Station and during a mission to Mars.

Introduction

To the extent that the effects of multiple stressors are involved in the degradation of human performance in Space, as suggested by the results of Watt (1997) among others, cognitive psychology can help solve the problem. In a retrospective piece, Rapmund (2002) describes how 20 years of experience working in the Pentagon convinced him of the need for a greater understanding of human behavior and of human-machine interactions to improve military operations. Wastell and Newman (1996) have argued that a well-designed military system should realize the twin aims of enhancing human performance and lowering stress. Success in this endeavor, they demonstrate, depends on the degree of support and controllability the system affords the operator.

Cognitive psychologists study things that people do in their heads and how they subsequently perform based on those mental operations. Cognitive psychology is largely an academic discipline and a basic science, concerned primarily with (a) identifying analytically the fundamental components of mental life, such as attention and its allocation, memory systems, problem solving, decision making and the like, (b) constructing experimental paradigms to isolate and examine these components in the laboratory, and (c) developing theoretical structures that help to make sense of the data collected in these paradigms. But the field is not exclusively academic. General principles have been uncovered over roughly the last forty years of laboratory research on cognition and some of those principles show promise of fruitful application to natural situations, especially in education and training.

Cognition in Emergency and other Abnormal Situations

One important issue to which contemporary cognitive research might usefully be addressed is behavior under stress and in emergencies or other abnormal situations. Interest in this problem is not new, having been expressed throughout the history of psychology as an independent discipline and particularly by governmental agencies and the military, which are especially concerned about performance of people in extraordinary conditions (see, eg., Dearnaley & Warr, 1979).

Emergency situations are almost always <u>dynamic</u>, because early actions by a participant determine the environment in which his or her subsequent decisions must be made. Further, features of the task environment may change independently of the participant's actions. Emergencies are <u>time-dependent</u>, because decisions must be made at the correct moment in relation to environmental demands. Emergencies tend to be <u>complex</u>, in the sense that most variables are not related to each other in one-to-one manner. Finally, emergencies are <u>stressful</u>, because they can create intense psychological pressures on participants.

Acute and chronic stress

Emergencies typically are not single isolated events. They are more like episodes extending in time. Thus, emergency situations often require not one decision about how to react, but a long series of decisions, and these decisions are, in turn, at least partly dependent on one another. For a task that is changing continuously, the same action can be definitive at one moment and useless at another. People often perform badly in emergencies, sometimes neglecting to respond correctly in even the most obvious ways. One bad decision can worsen the situation and augment the importance of later decisions. A poor decision or an inadequate response can compound the stress effects that are a consequence of the emergency itself. Being able to respond rapidly and correctly is clearly a distinct advantage to anyone caught in an emergency. Neufield (1999) has recently offered a promising formalism, based on nonlinear dynamics, that helps us understand the interaction of multiple variables operating over time, as in emergencies and in cases of stress and coping with stress. But there are presently few data available to test the adequacy of Neufield's theory.

Emergencies often create acute conditions of stress, but these effects subside after the emergency has passed. Other conditions that are non-normal but might not involve emergencies can also be stressful. Many of these conditions generate longer term or chronic, in contrast to acute stress. Among these conditions are space flight, confinement, isolation, and other similar protracted exposures to abnormal circumstances. Anecdotally, human beings have demonstrated an exceptional ability to live, work, and adapt to extreme environments. Sauer, Hockey, and collaborators conducted a series of studies of health and performance changes in chronically stressful circumstances. For example, Sauer, Juergen, Hockey, and Wastell (1999) reported a study of three Russian cosmonauts, tested on a PC-based simulation of a MIR space flight, including isolation and confinement over time. They found some temporary performance degradations as time passed although for the most part, without the occurrence of emergencies, job performance was acceptably high. The same researchers also reported on the

effects of wintering-over by a group of French Antarctic expeditionaries. They, like Brubakk (2000), argued that polar expeditions provide a better, more natural model of life in Space than do confinement or isolation studies. Again, only small decrements in performance on cognitive tasks were observed. Zulley (2000) reviewed the results of experiments performed in a wide variety of long-term isolating environments including Space, focusing on the circadian course of variables such as body core temperature, sleep-wake patterns, mood, and performance. He concluded that subjects in isolation can experience disturbances of sleep, mood and vigilance if their biological rhythms run "out of phase." On the basis of his review, he recommended that, if at all possible, a strict 24-hr. time schedule should be kept with regard to environmental, as well as behavioral influences to insure adequate and restful sleep and optimal levels of waking performance and psychological well-being. Again, no serious degradation in performance tasks attributable to isolation was reported, however.

The job of a commercial airlines pilot is generally regarded as one of the most stressful. It would, therefore, not be surprising to discover that pilots suffer more health problems than non-pilots. Nicholas, et al. (2001) investigated self-reported disease outcomes among a large group of active and retired commercial airline pilots in the United States and Canada. Increased disease rates among pilots were suggested for melanoma, motor neuron disease, and cataracts. However, rates for other diseases were in general lower than those for the U. S. population. As with others who are exposed to stress over extended periods of time, commercial airline pilots appear to adapt well and to evidence few serious behavioral problems as a consequence of job-related stress.

The counterintuitive message from this research seems to be that if participants are well prepared for the required tasks and understand that their confinement or isolation, while protracted, is time-limited, performance holds up well. Adaptation to chronic stress might be quite good, if the stressful situation is not prolonged indefinitely. If adverse conditions do persist, however, and there is no clear end-point to the stressful circumstances, there are at least some indications

of possible significant cognitive effects, especially in children (Haines, Stansfeld, Job, Berglund, & Head, 2001), What unique effects emergencies, occurring during chronically stressful conditions, might have are not clear from these studies. However, it is also the case that prolonged work stress in relatively mundane work settings can have significant effects on a person's health, especially if the stress creates chronic supra-optimal levels of arousal accompanied by a state of strain in the worker. Straining has been shown to put the performer at some risk regarding health and/or safety (e.g., Andries, Kompier, & Smulders, 1996). High correlations have been found between work stressors and psychosomatic complaints, general health, and felt fatigue and boredom at work (Houtman, Bongers, Smulders, & Kompier, 1994).

Teamwork under Emergencies

Many emergency situations require teamwork and co-ordination among two or more players. Cockpit emergencies, for example, usually do not happen to a single individual but rather to a crew. The stress associated with the emergency is generated within each crew member, but its most important influence might be on the performance of the crew as a whole. Decisions and responses might be made by individuals but their effects ramify throughout the team. Thus it is imperative to try to understand not only the individual under stress but also how the team functions cognitively in these circumstances. Unfortunately, the literature on this issue is quite limited and largely inconclusive.

The Purpose of this Review

Research in cognitive psychology has made a contribution to a understanding of acute and chronic stress effects on performance by identifying some of the factors that contribute to operator error under emergency or other abnormal circumstances and by suggesting how operators might be trained to respond more effectively in these circumstances. The major purpose of this paper is to review the literature of cognitive psychology as it relates to these questions

and issues. Because older reviews are available (e.g., Hamilton, & Warburton (1979; Hockey, 1983), we limited our search of the literature to roughly the last 15 years (1988-2002). To anticipate our findings, research published in this time period, as well as the earlier literature, is limited in significant ways. There are many studies to document the effects of stress on cognition, performance, and health, and most indicate stress effects to be adverse. Typically, however, these studies compare only two conditions, stress and no stress. Outside of the clinical literature, there are very few studies that examine stress over a wide range of values. This itself is surprising in view of the fact that most theoretical accounts of stress effects in psychology invoke some variation of the inverted U-hypothesis, that is, that there is some optimal level of stress (or arousal) for performance in any task. To verify such a hypothesis, at least three levels of stress must be included in the experiment. The literature is limited in still other ways. Although there are many experiments to document that stress does influence performance, there are very few that assess ways to prepare for or to countervail the effects of stress. That is, we know very little about steps that might be taken to inoculate the performer against stress. There is some literature on training to manage stress when it occurs, but only a few of these studies touch on the benefits of stress management for cognition or performance. Thus, in anticipation of the review to come, its outcome, in the form of a clear and well-documented depiction of the stress/cognition relationship and of recommendations for procedures or guidelines that might be followed to minimize or eliminate adverse stress effects, will be disappointingly meager.

As an aside, we expected to find the most significant research on stress and cognition published in the major cognitive journals, e.g., Cognitive Psychology, Memory & Cognition, the Journal of Experimental Psychology: Learning, Memory, and Cognition, and similar others. In fact, however, there has been relatively little published on stress in these Journals in the last 10-15 years. Rather, the most important publications that we found appear in peripheral journals, e.g., Aviation, Space, & Environmental Medicine, Ergonomics, Work & Stress, and the like. There are also many unpublished technical reports available in various data

bases. Our review uses few of these technical reports for a number of reasons, most important among them being their lack of peer review and the fact that the best of them often appear later in revised form in a peer-reviewed journal.

Preliminary Guidelines from Cognitive Psychology

An emergency, especially a life-threatening emergency, is a unique challenge to operators of complex systems, such as aircraft. On the one hand, pilots and crew-members are expected to maintain a high degree of proficiency in the relevant emergency procedures, such that their performance is virtually automatic. Yet, on the other hand an air crew rarely has an opportunity to practice these procedures in natural circumstances. In aviation, normal flight procedures that are carried out on a daily basis are completed with the benefit of a physical checklist. Emergency procedures, in contrast, are expected to be performed rapidly, accurately, and without external guidance. In addition, the procedures required might not be known if the conditions of emergency are unique. Studies of memory, conducted within the context of the cognitive psychological laboratory, have a good deal to say about this difficult situation. For one thing, it is not feasible to expect that even a highly experienced operator can execute flawlessly a complicated sequence of actions, which have not been recently refreshed, in response to an unexpected and threatening event (Bahrick, Bahrick, Bahrick,& Bahrick, 1993; Healy & Bourne, 1995). We will attempt to review and organize this experimental memory literature in such a way that the general principles can be identified and translated into guidelines for cockpit procedures. To the extent that we are successful, the result should have important implications for procedures and checklist design and for air-crew training.

Cognitive psychology has produced some promising leads on the effects of stress on human performance. Consider the most general question, what is the nature of responses under stress? The answer is, there is a vast amount of variability in performance. This variability depends, among other things, on who the operator is (a matter of individual differences) and on the situation in which

responding takes place (especially, the type of stress, e.g., time pressure, external threat, etc., engendered). There is evidence for a continuum of performance, ranging from: (a) no effect (the person handles the emergency situation as he or she would in the absence of stress) to (b) facilitation (a small amount of stress actually improves performance), to (c) varying degrees of degradation (the person makes errors or inadequately slow responses) to (d) choking (characterized by performance failure due to "overthinking" the problem and attending to aspects of the situation that are irrelevant to the task at hand) to (e) outright panic (resulting in primitive ineffective responses, as if no training had ever been given, or complete paralysis). It is obvious that, quantitatively, the intensity of stress elicited by an environment event should move people, in general, from the no effect through various intermediate stages to the panic end of the continuum. It goes without saying that, to determine this effect, objective measures of stress intensity are required. Moreover, people differ in how they respond to the same environmental event. We expect that, by disposition, some people handle stress better than others, and we will present in later sections some organized documentation to that effect. In addition to dispositional sources, individual differences created by training also affect where a person falls on the performance continuum. Degree of original learning or overlearning on the task at hand probably can mitigate some effects of stress, especially at lower stress levels. It seems obvious that skilled procedures that can be engaged on demand and executed flawlessly under normal circumstances stand the best chance of succeeding in an emergency or other abnormal situations. The literature to back this conjecture up will be reviewed.

Assuming that stress generally will, at some point, degrade performance, even well-trained performance, where in the cognitive system are these effects most likely to be found? Perception, attention, memory, decision making, problem solving and response execution, all stages that have been identified and studied by cognitive psychologists, are candidates for degradation. There is a relevant basic science literature on these cognitive processes, both empirical and theoretical. But the relevance of this literature to the natural emergency situation is limited by two factors. First of all, cognitive psychologists, in addition to identifying the

underlying processes of cognition, have developed laboratory tasks in which to study them individually, more or less uncontaminated by other processes. Thus, there are "attention" tasks or "memory" tasks in which attention or memory is revealed while other processes are eliminated or controlled. These tasks have become standard and are used widely over different laboratories. This has the advantage of providing a check on the replicability of data collected in different locations replicable. But, at the same time, it entails the disadvantage of creating relatively simple tasks that bear little face resemblance to things people do in the real world. Secondly, it is difficult to create real emergencies in the laboratory. Stress manipulations used by cognitive psychologists are mild and marginal, relative to natural emergencies. Both limitations make generalizations from the laboratory to behavior in natural emergencies risky and questionable.

To date, cognitive psychology has shed little light on performance in situations that require the concurrent management of multiple skills. Piloting an airship is one such situation that is characterized by many relevant variables, differing lags in system components, and several independent, simultaneous tasks. O'Hare (1997) and Wickens (2002) have written extensively on this matter. At the top level, successful performance in piloting requires simultaneous awareness for one's position in space, of the state of the many variables comprising the operations system, and of the various task requirements. These competing demands often exceed the operator's finite attentional resources. The PC-based WOMBAT-super(TM) Situational Awareness and Stress Tolerance Test has been designed to measure individual aptitude to cope with such demands (O'Hare, 1997). Because of the high mental workload imposed by flight, a pilot might fail to maintain full awareness of the environment and, at various times, neglect certain critically important component tasks. Performance on the WOMBAT test reliably distinguishes between elite pilots and similarly experienced but less skilled pilots (O'Hare, 1997). Loss of awareness has been identified as a major contributor to human error in aviation accidents (Li, Baker, Lamb, Grabowski, & Rebock, 2002). Moreover, there is no doubt that loss of awareness can be stressful. Indeed, anticipation of possible loss of awareness might be stressful, leading to some cases

of performance degradation or errors as arousal increases. Wickens (2002) has described the cognitive processes involved in piloting an aircraft and the changes in them that come with cockpit challenges. He notes that basic experimental cognitive psychology has produced a reasonable understanding of these processes in isolation or in simple (dual task) combinations. But presently we lack a full understanding or successful modeling of the complex interactions among these processes that occurs in many natural situations.

That having been said, it is still the case that basic cognitive research has identified some important general principles regarding stress and performance. These principles are known to apply when individual cognitive processes are isolated and studied analytically. To the extent that these processes are involved in more complicated naturalistic emergency situations, the principles so identified have something to say about behavior in emergencies. In other words, they should help us to understand and account for behavior of persons in real situations. Beyond that, we will be able to abstract out of this basic literature some useful recommendations about procedures and guidelines for effective performance in real emergency situations.

<u>An Example</u>

An example might be useful at this point. Cognitive research currently is concerned with a variety of forms of memory. One important distinction applies to the temporal focus of information retrieved from memory. This distinction is based on a continuum from the remote past – retrospective long term memory – to the present or near present – short term memory and immediate or working memory – to the future – prospective memory. Long term memory is theoretically a repository for facts and skills acquired in the past. Short term and immediate memory holds facts and skills that are currently at the focus of attention. Prospective memory contains reminders of actions to be executed at some future time and place. Laboratory tasks have been invented to study each of these forms of memory and the factors that influence them. The fundamental processes and the

important variables influencing memory are not necessarily the same in all cases. Long term memories are characterized, for example, by loss of detail and partial retrieval whereas immediate memories and especially prospective memories are more likely to be all-or-none, i.e., complete or absent. Whether the memories in question relate to facts (episodic memories) or skills (procedural memories) is also an issue. Specific fact memory tends to blur into generic representations over the long term, whereas skill simply degrades to lower levels of achievement.

Stress effects have been studied in the context of various forms of memory, although the data available are surprisingly skimpy. The evidence seems to suggest that stress in general (including stress arising in emergency situations) causes the operator to focus on the here-and-now, with consequent degradation in retrospective and prospective memory. The results are consistent with a memory constriction hypothesis to the effect that the time span from which knowledge can easily be retrieved and used in a given context shrinks as stress level increases. Neglect of facts or procedures in long term memory and failure to execute required behaviors at appointed future times might be major reasons for performance errors or failures in emergencies. At the present time, empirical evidence to support this hypothesis is weak. The hypothesis could, however, serve as a framework for future research efforts.

Research Methods

In the review that follows, our focus will be on the basic science literature. But we will not exclude naturalistic observations and case studies. To the extent possible we will examine the naturalistic decision making and problem solving literature in an attempt to find parallels with what has been learned in the laboratory. In fact, as noted above, the basic literature in cognitive psychology is quite disappointing. Basic researchers seem to have lost interest in stress during the last 15-20 years, judging by the number of publications in the prime journals. Consequently, we have broadened the search, and will reference articles in sports psychology, health, organizational and industrial psychology, human factors,

aviation psychology, psychophysiology, ergonomics and other areas. We have found a considerable literature on situation-specific stress, as in stress in the workplace, in the office, among high level managers, in military operations, in airplanes, among air traffic controllers, in autos while driving, in buses, among police and firefighters (see, e.g., Raggatt & Morrissey, 1977; Westman, 1996; Westman & Eden, 1996; Zeier, 1994), but again the general implications are limited.. The research in these peripheral areas tends to be limited and a little simplistic, involving two-group comparisons (stress/no stress), biological correlates of stress, case or correlational studies, intervention studies, and while the literature is considerable, it does not tell us much about basic or practical principles.

Measures of Stress Effects

Neuro-physiological Measures of Stress

Situations capable of initiating physiological stress responses are varied and complex. In the animal literature, stressors have been classified into two categories (Herman & Cullinan, 1997). One category, termed "systemic" stressors, includes many situations that produce direct physiological threats to organisms. Instances of such situations include microbial infections, temperature extremes, dehydration, injuries, and malnourishment. The second category, termed "neurogenic" or "processive" stressors, includes situations that do not immediately threaten an organism's physiological homeostasis but are perceived as a potential threat. In human beings, instances of processive stressors include psychological and psychosocial situations, requiring significant cognitive processing for their interpretation. In the lives of human beings, the most common challenging situations encountered are in the processive category. Traumatic-life events such as bereavement or anticipated or actual loss of home are familiar examples, but less traumatic events, such as performance anxiety associated with public speaking and examinations, as well as psychosocial pressures from interpersonal relationships and work place settings, are also effective activators of physiological stress

responses. Most challenging laboratory situations fall into the processive class of stressors. Such laboratory settings range from cognitive situations demanding high levels of performance on mental arithmetic or the Stroop color-word interference test, to psychosocial situations involving public speaking, interviews, and the presentation of violent videotapes. Biondi and Picardi (1999) in a recent review of the human literature regarding the effects of real-life and laboratory stressors on neurohumoral functions, emphasized the importance of situational appraisal and emotional reactivity as triggers of several stress responses, as originally suggested by others (Lazarus, 1966; Mason, 1975). The most emotionally "loaded" procedures are thus the ones associated with the strongest physiological stress responses. This association supports the need to examine self-report measures of stress and their correlation with physiological stress responses in future studies.

There are several physiological responses that are reliably correlated with the experience of stress and with stressful physical stimuli. This repertoire of responses plays an important role in preparing individuals to cope with putative internal or external stimuli that might threaten their well being or survival. Threats to homeostasis are met by acute physiological responses that are quick and engage two main biological systems. The first is the sympathetic division of the autonomic nervous system, which controls neural and hormonal processes. Acute psychological stressors generally activate the sympathetic adrenomedullary system. The release of the adrenomedullary catecholamine hormone, adrenaline, is crucial in the preparation of an individual's "fight or flight" reaction, as first suggested by Walter B. Cannon (1932). Additional sympathetic neural activation via noradrenaline release is responsible for a variety of peripheral responses associated with stressful situations, including, but not limited to, increases in heart rate (HR), blood pressure (BP), respiratory rate, perspiration, and inhibition of digestive and sexual functions (Cacioppo, 1994).

The second principal stress-responsive system is the brain-pituitary-adrenocortical axis, which regulates the release of glucocorticoid (GC) hormones into general circulation (Akil, Campeau, Cullinan, Lechan, Toni, Watson, &

Moore 1999). Two of the most salient hormonal responses to stress are increases in norepinephrine and cortisol, GCs manufactured and released by the adrenal cortex. But stress is associated with a number of other neurohumoral responses. For instance, stress increases the release of growth hormone and prolactin and inhibits the release of the thyroid and sex steroid hormones. Many of these hormonal modulations have been linked to the release of cortisol (Nemeroff, 1992). The orchestration of these responses allows the inhibition of "vegetative" functions while activating energy metabolism, body defenses, blood flow to the skeletal muscles, and a sharpening of the senses. Farrace, Biselli, Urbani and Ferlini (1996) have demonstrated the usefulness of these processes in the evaluation of stress responses during flight.

Stress also affects the human immune system. Although chronic stress typically produces suppression of a wide range of immune system parameters, acute stress has been found to stimulate certain aspects of immune functioning (McEwen, 2000). Specifically, acute stress can trigger aspects of an immune system acute phase response, even in the absence of an infectious agent (Deak, Meriwether, Fleshner, Spencer, Abouhamze, Moldawer, Grahn, Watkins, & Maier, 1997). This acute phase activation results in a rapid increase in blood levels of certain acute phase proteins, as well as production and secretion into the blood of the immune system related hormone, interleukin-6 (Zhou, Kusnecov, Shurin, DePaoli, & Rabin, 1993). Thus, acute phase activation is potentially another physiological marker of stress that might be useful in human studies. Recent animal studies have provided evidence for stress-induced stimulation of the acute phase response to be at least partially responsible for stress-induced impairments in memory consolidation (Cahill & McGaugh, 1996; Pugh, Nguyen, Gonyea, Fleshner, Watkins, Maier, & Rudy, 1999). These studies support accumulating evidence for brain activity to be dynamically regulated by immune system factors (Maier, Watkins, & Fleshner, 1994).

Electrical activity in the brain, as reflected in EEG patterns, are sensitive to certain abnormal human conditions such as alcohol intoxication and fatigue.

Gevins and Smith (1999) reported that both intoxication and fatigue reduced the accuracy of performance in a working memory task and that these effects were associated with changes in spectral characteristics of the EEG. These authors have shown that both human observers, operating intuitively, and computing networks trained on human data can discriminate EEG patterns associated with fatigue and alcohol states from normal alert states with accuracy well over 90%.

Measures of physiological responses can serve at least three distinct purposes. First, they can help independently to determine the challenging or stressful character of experimental circumstances. They can be used to assess the degree to which the manipulations produce stress independent of the subjective exit interviews and self-report indices. These physiological measures may offer a rigorous between-experiment assessment of the stressful character of the different conditions employed in the laboratory. A second feature of these measures is that they permit an assessment of correlations between physiological and cognitive variables. For example, do the changes produced by stress in cognitive performance relate significantly to concomitant changes in particular physiological responses? Third, these measures will allow the investigation of possible mediating relationships between physiological states and cognitive functioning. For example, a given physiological state may not just mark stress but may mediate the effects of stress on performance. Intrinsic circadian variations of stress-reactive hormonal levels could be tested to reveal possible mediating effects of such physiological states upon performance, although this research is yet to be conducted.

To measure physiological reactions to stress, the following procedures have been most frequently used and seem most useful. First, with respect to the action of the sympathetic nervous system, researchers have measured a variety of peripheral response measures, including, but not limited to, increases in HR, BP, respiratory rate, perspiration, and inhibition of digestive and sexual functions. These indices are probably most familiar as components of the lie detection procedure. Although they can be controlled cognitively, subjects typically have no

reason to attend to these measures while engaged in a focal task. Under these circumstances, peripheral measures have proven to be highly and reliably correlated with other indices of stress level. There is a good deal of research to document the existence of distinct patterns of autonomic nervous system reactions to stressful events (e.g., Lovallo, Pincomb, Brackett, & Wilson, 1990; Saab & Schneiderman, 1993). People who appraise potentially stressful events as challenges show a reaction consisting of high cardiovascular activity coupled with low vascular resistance. Individuals who appraise the same events as threats show low to moderate cardiac activity and high vascular resistance. Veltman and Gaillard (1996, 1998) investigated the sensitivity of some of the same physiological measures to mental workload in a flight simulator. Several respiratory parameters, HR variability, BP variability, and the gain between systolic BP and heart period all showed differences between rest and flight. Only heart period was sensitive to difficulty levels in the flight task. Among the respiratory parameters, the duration of a respiratory cycle was the most sensitive to changes in workload. Finally, the time between two successive eye-blinks increased and the blink duration decreased as more visual information had to be processed.

Second, to tap the brain-pituitary-adrenocortical axis, researchers have measured GC cortisol in the saliva of human subjects. This is a noninvasive measure and can be repeatedly sampled in most experiments (Kirschbaum & Hellhammer, 1994). Salivary cortisol is closely correlated with free plasma cortisol levels (Vining & McGinley, 1987), and is useful in detecting several forms of acute stress in the laboratory or in the field (Aardal-Eriksson, Karlberg, & Holm, 1998; Bassett, Marshall, & Spillane, 1987; McCleery, Bhagwager, Smith, Goodwin, & Cowen, 2000), including challenging military training (Morgan et al., 2000). Level of testosterone, which has been shown to be significantly reduced by some stress procedures (Elman & Breier, 1997; Hellhammer, Hubert, & Schurmeyer, 1985; Schulz et al., 1996), can also be measured in saliva of male subjects. Similar determination using estradiol in adult women is usually not warranted because of low correlations between plasma and salivary levels with

existing assays and collection methods (Shirtcliff, Granger, Schwartz, Curran, Booth, & Overman,2000)). The immune system cytokine product interleukin-6 (Il-6), which is elevated in response to a variety of stressors, is another marker of stress measurable in saliva. Salivary Il-6 determination has been reported to correlate highly with the release of cortisol in at least one study (Perez Navero, Jaraba Caballero, Ibarra de la Rosa, Jaraba Caballero, Guillen del Castillo, Montilla Lopez,Tunez Finana, & Romanos Lezcano,1999).

An important issue concerning the various hormonal responses to stress is the fact that cortisol shows a significant circadian rhythm in human beings (Czeisler & Klerman, 1999). Thus, circulating cortisol levels normally rise and peak during early morning in anticipation of waking and the demands that the waking state produces on energy consumption and metabolism. Circulating cortisol levels thereafter drop throughout the day and are at their lowest in the evening, anticipating the reduced energy expenditure during the sleep period. Any activation of the adrenocortical stress axis is therefore superimposed on this daily rhythm, and the assessment of morning stress can easily be clouded by the already high morning circulating levels.

Despite the difficulties and the complexity of taking physiological measures, they are recommended for any research program that aims to provide a complete picture of the role of stress in human cognitive performance. It should be noted that the strength of a stressor can only be determined by measuring the subjective and physiological response of the individual, because individuals may vary widely in their reactivity to stressful circumstances. Where possible, it is important to determine the extent to which subjective reports of stress correlate with physiological measures. Likewise, it is important to see whether subjective or physiological measures of stress responses are reliable predictors of performance on whatever task is being studied.

Self-report Measures

Stress affects how we perform (behavioral), how we feel (self-report), and many of our bodily functions (neuro-physiological). All three then should be able to serve in some capacity as measures of stress, independent of environmental or physical conditions that are said to be stressful. Systematic and exacting experimental studies of stress and its effects on cognition require valid and reliable measures that can be taken both in the laboratory and in the real world. The best work available on the evaluation of subjective states of stress has been reported by Matthews and his collaborators (e.g., Matthews, in press; Matthews, Joyner, Gilliland, Campbell, Falconer, & Huggins, 1997).

Matthews et al. (1997) noted that research on the subjective state of stress, until recently, has been limited in scope, focusing primarily on state anxiety and mood. These authors developed a broader index known as the Dundee Stress State Questionnaire (DSSQ) which provides the first comprehensive multi-dimensional assessment instrument for transitory states associated with stress, arousal, and fatigue. Construction of the DSSQ began with a factor analyses of various paper and pencil measures of stress, available in the literature or developed by the authors. These scales represented three primary categories which the authors refer to as mood measures (focusing on arousal, tension, and hedonic tone), motivation measures (especially intrinsic motivation or interest in the task at hand), and cognition measures (including awareness, interference, self-focus, concentration, and confidence). By factor analysis, these scales generated three secondary dimensions of subjective stress reaction. The first is labeled Task Engagement by the authors, and is described in terms of how much energy, and concentration a person invests in a task. The second is labeled Distress, that is, how much tension, the hedonic tone, and the confidence a person exhibits in task success. Finally, Worry, or the degree of self-focus and self-esteem expressed and the amount of cognitive interference experienced from intrusive memories and other sources (see, e.g., Baum, Cohen, & Hall, 1993). Refined scales were then developed to give maximally discriminant measures of Engagement, Distress, and Worry.

Matthews et al (1997) demonstrated empirically that these state dimensions are independent of other state or trait measures available in the personality literature, such as neuroticism. They further showed that these measures are sensitive to external stress manipulations, especially in challenging and demanding tasks. Task engagement scores are high when task demands are intense and the task itself provokes strong intrinsic motivation. Distress is most closely related to capacity overload and time pressure. Demanding tasks are typically distressing, especially when they are appraised as threatening. Finally, worry tends to be associated with self-evaluation as when the nature of the task provokes assessment of personal qualities and goals. But, boring or monotonous tasks or tasks that lead to a loss of concentration can also provoke worry. Matthews et al. (1997) have developed a processing efficiency theory that predicts slower memory scanning and retrieval in subjects with high chronic stress or high anxiety, because some of the working memory capacity of these subjects is occupied by worries, more than low anxious or nonstressed subjects. Ashcraft (2002) has attempted to test this theory directly, and reports inconsistent results. But the hypothesis is plausible and deserves further empirical investigation.

Basically, Matthews, et al. (1997) have shown that much of the variation in the subjective stress state can be characterized by the three themes, labeled commitment to the task, cognitive overload, and self-evaluation, all of which are accessible by self-report. Matthews (1996) suggested that these themes represent the three principal adaptive challenges posed by stressful performance environments and that basic state reactions reflect choices of adaptive strategy within a variety of different situations. The evidence supporting the validity and reliability of the DSSQ is extensive and impressive. As noted above, it represents the most comprehensive measure of subjective stress presently available. Its utility in research might be limited, however, by the length of the questionnaire and the time required to administer it, which is estimated to be approximately 10-15 mins. If stress measures can be taken before or after the fact, then the questionnaire is probably the best instrument available. If stress measures are required concurrently with stress conditions and/or on a moment-by-moment basis, other

less reliable indices will probably be necessary. It might be possible to develop a short-form instrument, based in the DSSQ, that could be used for concurrent measurement, but such a test has yet to be published.

Task induced changes in stress are described within Matthews' system as patterned shifts in task engagement, distress, and worry. Patterns are sensitive to task and environmental demands. Matthews et al. illustrated this effect with studies of automobile driving. Operators' appraisal of task demands (workload) and choice of coping strategy mediate these stress effects. Thus, for Matthews, stress is an adaptive transaction between operator and task. Matthews et al. speculate that the consequences of task automation (e.g., cockpit automation) will vary widely depending on appraisal of the reliability and ease of control of the system, type and number of residual tasks left to the operator, and interpersonal factors such as personality and coping style. Thus there is likely to be no simple remedy for stress-related problems associated with automation, such as boredom or complacency. Fine-grained assessment of the operator's feeling state and cognitions is required to determine vulnerability to performance degradation under stress.

Evidence from Matthews et al. (1997), based on self-report measures, supports the following guidelines for mitigating the effects of stress in automated and semi-automated systems, such as driving an automobile or flying an airplane.

Delineate and focus on those actions and problems that are subject to operator control.

Recognize that there are qualitatively different stress-reactions that require different interventions. Stress attributable to fatigue and task disengagement are different from those attributable to distress or worry.

Design the system with stress factors in mind. For example, avoid overload on operator controlled tasks.

Design for variablity of work load requirements.

A number of specific self-report techniques have been developed to measure stress in the work place, and some of these have possibilities as general stress measures. Quick (1998) has provided an excellent summary of these measuring devises, which include the following.

(1)   The Occupational Stress Indicator and its successor, the Pressure Management Indicator (PMI, Williams & Cooper, 1998). The PMI presents a range of 22 sub-scales that tap into a number of aspects of the organizational stress process, from demands through moderators and modifiers to strain and distress responses. The PMI also provides information on organizational constructs such as organizational climate and individual constructs such as personal responsibility.

(2)   The Job Content Questionnaire (JCQ, Theorell & Karasek, 1996; Karasek, Brisson, Kawakami, Houtman, Bongers, & Amick,.1998).), which is a perceptual measure of social and psychological characteristics of jobs and the content of work.

These questionnaires are reliable and valid self-report measures, but are less comprehensive, and therefore less valuable as research tools than the battery developed by Matthews et al. (1997).

How do self-report measures of stress stack up against neuro-physiological indices? Leaving aside for the moment the time it takes to recover these measures, the answer is, quite well. In fact, under many circumstances, self-report measures are to be preferred because of their greater face validity and reliability. There are several studies in the recent literature that speak to this issue. For example, Zeier (1994) reported a study that used both self-report and neuro-physiological measures of stress in air traffic controllers. He found that periods of high and low traffic differed in both self-reports and in levels of salivary cortisol. Further he found a high correlation between self-reports and cortisol levels. He concluded that, while these measures differ in substantive ways, the information they provide

is supplementary and neither is to be preferred over the other. Both measures might be valid reflections of the same underlying processes.

Shostak and Peterson (1990) found that self-report measures of anxiety level were more sensitive and more reliable as predictors of simple laboratory performance than were two physiological measures, HR and BP. These researchers concluded that self-report measures were further to be preferred in this context because they were easier to take. Kozena, Frantik, and Horvath (1998) reported a similar outcome using middle-aged train drivers. Questionnaire data on health state and family health history, lifestyle, job stress, social and family support, personality characteristics, and health risk behaviors were more predictive of performance in reaction to laboratory stress than were measures of cardiovascular activity, including HR and BP.

Performance or Behavioral Measures

But the issue of which type of measure, self-report or neuro-physiological, is the better or more appropriate measure of stress effects is far from settled. Hancock and Vasmatzidis (1998) contend that, rather than either self-report or physiological measures, task performance level should be the primary criterion for determining the effects of exposure to stress. They argue that change in behavioral performance efficiency is the most sensitive reflection of human response to stress, and that error-free performance is the principal criterion of work efficiency, especially in high-technology systems. Therefore, continuing exposure to stress after work performance efficiency begins to fail, but before current physiological limits are reached, is inappropriate for both the safety and the productivity of the individual worker, their colleagues, and the systems within which they operate. Behavioral performance assessment should therefore supercede physiological assessment or self-report as the primary exposure criterion, although these other measures still provide important supplementary information.

There are, of course, others who disagree with this analysis, contending that how a person thinks and communicates about stress and/or how the body automatically reacts to stress are fundamental components of the stress syndrome that are not contained within measures of performance. Still, there have been several significant efforts, following the logic of Hancock and Vasmatzidis, which have been aimed at identifying and developing reliable performance measures to assess individual differences in reactivity to stress. Ackerman and Kanfer (1994) developed a battery of cognitive ability tests for predicting performance under stress. As a test bed, they used a dynamic Target/Threat Identification Task performed under time-pressure. Their final battery consisted of a mixture of cognitive and perceptual speed ability and stress-reactivity measures. They showed that these measures accounted for the major amount of individual differences in performance on a variety of complex tasks. Two tests, called The Dial Reading and Directional Headings Tests, were found to be particularly promising predictors of performance in stressful information processing activities. The authors concluded that such measures have definite advantages over self-reports in predicting individual differences in reaction to stress.

A somewhat different set of measures was used by Thomas, Schrot, et al. (1995). Cognitive processes of primary interest to these authors were memory, speed of response, vigilance, mental calculation, reasoning, and learning. The measures of performance they examined were matching-to-sample, complex reaction time, visual vigilance, serial addition-subtraction, logical reasoning, and repeated acquisition of S-R associations. These measures were implemented in a standardized manner on portable battery-operated computers for use in both laboratory and field settings. Their report provides detailed documentation, supporting the reliability and the sensitivity of these measures to stress effects in a complex operations environment.

Conclusions[1]

Several physiological responses are reliably correlated with the experience of stress and with stressful physical stimuli. One arises in the autonomic sympathetic nervous system, which controls both neural and hormonal processes The second principal stress-response system is the brain-pituitary-adrenocortical axis, which regulates the release of GC hormones in the general circulation. Two of the most salient hormonal responses to stress are increases in norepinephrine and cortisol, GCs manufactured and released by the adrenal cortex. Third is the immune system, which is also sensitive to stress. Although chronic stress typically produces suppression of a wide range of immune system parameters, acute stress has been found to stimulate certain aspects of immune system function.

Measures of physiological responses can serve at least three distinct purposes in research. First, they can help independently to determine the challenging or stressful character of experimental circumstances. Second, they permit an assessment of correlations between physiological and cognitive variables. Third, these measures allow the investigation of possible mediating relationships between physiological states and cognitive functioning. To measure physiological reactions to stress, the following procedures seem most useful. First, with respect to the action of the sympathetic nervous system, researchers have examined a variety of peripheral response measures, including, but not limited to, increases in HR, BP, respiratory rate, perspiration, and inhibition of digestive and sexual functions. Second, with respect to the brain-pituitary-adrenocortical axis, researchers have measured GC cortisol in the saliva of human subjects. The immune system cytokine product interleukin-6 (Il-6), which is elevated in response to a variety of stressors, is another marker of stress measureable in saliva.

The most successful self-report measures of stress focus on three processes: commitment to the task, feelings of cognitive overload, and self-assessment of success. Context-induced changes in stress result in patterned shifts in task engagement, distress, and worry on the part of the subject. Patterns are sensitive to task and environmental demands. Comparisons of the value of self-report to neuro-physiological measures of stress have been inconclusive. Most researchers find a high correlation between these two types of measures, leading to the conclusion that, while these measures differ in substantive ways, the information they provide is supplementary and neither is to be preferred over the other. Other researchers have argued that

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[1] Conclusions are written in a smaller font than the text. They can be read after the section to which they relate or collectively, in a section entitled Summary and Conclusions, at the end of the report.

changes in behavioral performance efficiency are the most sensitive reflection of human response to stress, and that behavioral measures are sometimes preferable to both self-report and neuro-physiological measures.

Definitions of Stress

Stress is a descriptive term used in both the behavioral and biological sciences to cover conditions of a physical, biological, or psychological nature, that typically cannot be controlled by organisms, and that strain organisms often beyond their powers to adapt (e.g., Gaillard & Wientject, 1994). But there is no single universally agreed to definition of stress and consequently no single measure that will tell us when a person is stressed or operating under stressful conditions (Hancock & Desmond, 2001). Some conditions have generally been accepted at stressful. For human beings, these include but are not limited to extreme temperatures, loud or noxious noises, infectious diseases, sleep deprivation, extreme heavy or prolonged work loads, time pressures, social pressures, and intense negatively-toned emotions. Stressors are environmental, biological, and/or cognitive events that, among other things, challenge or threaten the well-being of an organism, increase its arousal or activation level, and deplete its resources (see, e.g., Hobfoll, 1991). They can be extraneous (non-work stress) or indigenous (stress created by the task) and they can arise from endogenous or exogenous sources. The resulting stress states can be acute and time limited, as in responses to a single transitory event, or they can be chronic, as when the condition of stress persists in time. Normally, human beings respond to stressors either through extraordinary mental or physical effort or by exhibiting degraded performance. Extreme effort over time in response to chronic stress can result in either mental or physical exhaustion or injury (see, e.g., Kolich & Wong-Reiger, 1999).

With respect to human performance, stress-related phenomena are often classified as emotional, cognitive, and physical (Van Gemmert & Van Galen, 1997). There are numerous examples of the effects of stressors in all three categories affecting human performance. For example, regarding emotional stress, Adam and Van Wieringen (1988) have shown that worry and emotionality,

measured as personality traits, are negatively correlated with proficiency in a simple motor task. Cognitive stress, resulting from the need for coordinated multi-tasking in nearly all daily activity, is perhaps the most common stress condition. Heightened mental load resulting from multitasking typically slows responding, although it often has little affect of accuracy of performance (Castiello & Umilta, 1988). Physical stress is particularly interesting in the light of the contemporary concern with the quality of the natural environment. Urban areas in particular present stressors in the form of noise, air pollution, and disturbance of natural light/dark rhythms. But research has presented an unclear picture of the effects of these stressors, sometimes reporting significant detrimental effects on performance and health and sometimes reporting no effect (Nivison & Endresen, 1993; Smith, 1991). Interestingly, Van Gemmert and Van Galen (1994) showed that performance in a complex sensory-motor task was more sensitive to cognitive stress, manipulated by concurrent memory load, than to physical stress, manipulated by sound pressure level. These often conflicting results argue for a more comprehensive study of stress effects on human performance and for an integrative theoretical framework in which to organize the empirical evidence. This effort might profitably focus on the nature of the task to be performed and the strategies people use to contend with conditions of stress.

Theories of Stress and Cognition

In general, theories of stress account for its effects on cognition and on human performance in terms of multiple psychological and biological processes. These processes include, but are not limited to: arousal or activation (stress intensity is directly and linearly related to arousal level), attention allocation (stress controls directly or indirectly the distribution of attention across points of environmental and internal input and can overload attentional capacity), and plans or strategies for the deployment of attention and other resources. Theories differ in their assumptions about these processes. Some attribute little or no role to consciousness or awareness, asserting that stress effects are direct, automatic, biological, or intuitive. Others assign the major performance control functions to

plans, appraisals, analyses, and other cognitive phenomena that are invoked in stressful situations. These differences are illustrated in the following section, which presents a sampling of recent theoretical writing on the relationship between stress and cognition.

      <u>Cognitive Continuum Theory.</u> Hammond (2000) introduced what he calls a missing link in modern stress/cognition research, that is, a comprehensive set of principles under which stress effects can be classified, interpreted, and coherently integrated. Such a set of principles, if it can be articulated and agreed to, would be tantamount to a new theory and constitute a model for future research in the area. To set the stage for his theory, Hammond argues that the field has been characterized by two points of view regarding the proper focus of research (for a related argument, see Gigerenzer, Todd, and the ABC Research Group, 1999). The <u>Coherence</u> point of view incorporates models based on the assumption that human behavior is always contingent not only on the task at hand but also on intervening rational or quasi-rational thought processes. Models of this type include those based on statistical decision analysis, heuristics and biases, information integration theory, and the notion of multi-attribute choice. The coherence position leads to a research focus on the systematic interplay between a task or problem, thought processes it might elicit, and the eventual response. The <u>Correspondence</u> viewpoint incorporates models that are indifferent to intervening cognitive processes and that focus on systematic and direct relationships between task characteristics and responses, e.g., the empirical accuracy of a judgment. The theories cited as examples by Hammond are signal detection theory, probabilistic mental models, and the author's work on social judgment theory. The first approach emphasizes <u>analytical cognition</u> (deliberate cognitive processes) and the second approach emphasizes <u>intuitive cognition</u> (unconscious,, non-traceable cognitive processes) (see also Gigerenzer, Todd, & the ABC Research Group,1999).

      Hammond's theory of judgment and decision making -- the Cognitive Continuum Theory (CCT) -- is based on four principles, arising from the

correspondence and coherence metatheories and two theoretical terms, called intuition and analysis. Of further importance to this theory is the postulate that "tasks" are special concepts in and of themselves and have properties—"task properties" – that significantly interact with cognition. CCT requires the development of indices to codify both task properties (exogenous factors) and cognitive properties (endogenous factors). This is accomplished by considering cognitive activity to lie on a continuum from intuitive to analytical with a mid-point of "quasi-rational thinking" or "common sense". Tasks are likewise considered in light of their "capacity to induce intuition, quasi-rationality, or analytical cognition". This then produces a 3X3 matrix of task and cognitive properties onto which a particular cognitive event can be mapped

TASK CONTINUUM INDEX

COGNITIVE INDEX	INTUITIVE	QUASI-RATIONAL	ANALYTIC
INTUITIVE	Best		
QUASI-RATIONAL		Best	
ANALYTIC			Best (normal)

Stress is introduced into this model as a consequence of a disruption of "constancy" or balance or homeostasis between cognition and task (environment). Hammond proposes that all organisms seek to maintain stable relations within their environment and the disruption of stabilized relations produces what we know as stress. Stressors are divided into endogenous (any negative change within the task system, e.g. loss of an information source) and exogenous disruptions (those due to factors outside the task system (e.g., fire, noise, cold). The particular disruption (exo- or endo-) will, according to Hammond, affect the type of cognition and the consequences of judgment. Overcoming endogenous disruption of constancy demands cognitive change, i.e., moving along the 3x3 matrix, whereas overcoming exogenous disruption of constancy demands resistance to cognitive change and staying within the correct cell of the matrix. How to know when to "change" or

when to "stay" within a particular cognitive mode becomes the crux of effective problem solving, leadership, and judgment. The author contends that not only is this model highly researchable, but should also lead to methods of training that may be different for those being groomed for leadership roles.

Hammond claims that CCT provides a new orientation for the field of stress and cognition. He highlights four points: (1) Environmental events and cognitive events share equal and joint billing in the determination of behavior. (2) Stressors should always be examined in relation to cognitive activities. (3) Disruptions of homeostasis should be differentiated into endo- versus exogenous and the current cognitive mode recognized (intuitive/analytical). (4) Leaders and followers should be taught to be alert to and to accept the need for cognitive change. According to Hammond (2000), these principles provide a cohesive and coherent framework for organizing what we presently know about stress and cognition and the direction that future research in might take.

Theories of activation and resource allocation. Many theories of stress incorportate two mechanisms, one related to activation of the organism and the other related to resource competition. The first mechanism is typically assigned a facilitating effect generally describable as a "readiness to respond." The second can have a negative effect resulting from the necessity to spread cognitive or other resources thinly over various input and response possibilities. The combination of these two mechanisms allows the theorist to account for the sometimes paradoxical facilitative and inhibitive effects of the same stressor on performance. Facilitation occurs when the activation process dominates; inhibition when the competition process dominates. Facilitation generally occurs under mild to moderate stress and with simpler task requirements. Inhibition occurs at higher levels of stress and more demanding task requirements.

The form attributed to these mechanisms differs widely among theorists. A recent example is Van Gammert and Van Galen (1997), which is described here not because it is the most convincing theoretical argument but rather primarily for

purposes of illustration of recent theoretical developments regarding processes underlying stress. Van Gammert and Van Galen employ the concept of neuromotor noise to explicate the activation side of stress effects. But they also incorporate resource allocation and postulate ways in which activation and resource allocation interact.

Van Gammert and Van Galen assert that the human cognitive system is inherently noisy. But increased processing demands produce even larger levels of noise and consequently decreased signal to noise ratios in the system. That stress generates noise in the cognitive system is not a new idea, being first introduced by Mandler (1979). But Van Gammert and Van Galen develop the idea beyond earlier theoretical statements. According to Van Gemmert and Van Galen, the effects of noise can appear either in effectively reduced sensitivity to task related sources of information or on the motor side in the form of less exacting movements. Van Galen, Van Doom, and Schomaker (1990), for example, showed that, as the complexity of the sequence of movements required by a task increased, the contribution of tremors and other indices of neuromotor agitation also increased, resulting in a relative degradation of performance. But not all effects of noise are negative. Noise is also said to have an activating or altering function. Performance is assumed to be best at optimal levels of signal to noise ratio. Performers engage in various strategies to achieve these optimal ratios. One strategy is to slow down, permitting noise activation to level off relative to task-relevant activation. Evidence in support of this strategic maneuver comes from classical stress management techniques and from the considerable literature showing among other things that RTs to weak signals are typically slower than RTs to stronger but otherwise equivalent signals (e.g., Tanner & Swets, 1954). A second stress management principle states that, under conditions of stress, performers adaptively set motor system parameters to produce optimal signal-to-noise ratios for muscles and movement.

Noise effects, when they occur in resource pools, can adversely affect all concurrent tasks drawing on those pools. Noise propagates in the cognitive

system such that concurrent tasks are more affected by noise than are independent or sequential tasks. Further, the more closely related two or more concurrent tasks are, the greater the competition between them for resources. A potentially useful extension of this work has been provided by Neufield (1999), who developed a nonlinear formalism for describing multiple variables interacting over time, as in stress and performance.

Van Gammert and Van Galen (1997) tested some of these theoretical ideas in a series of experiments using both verbal (writing numbers in response to dictation) and spatial (aiming and drawing) tasks. Both tasks were performed under two types of stress, cognitive (performing a secondary arithmetic task) and physical (presence of a loud auditory noise). Three measures of performance were taken. Response initiation time, that is, time between stimulus and the beginning of movement, was used as an index of the difficulty of information processing. Movement time, that is, time to execute a response, was used as an index response difficulty. Hand pressure on manipulanda was used to measure tremor and motor stiffness. Both facilitative and inhibitory effects of stress were observed on initiation and movement time. Predictions from theory about resource competition, tremor interference, and time management were largely confirmed by these experiments.

Matthews and Desmond (1995) argue for a model of stress that incorporates three general mechanisms through which stress and the operation of complex systems may interact to affect performance, generally detrimentally. These are (1) overload of attentional capacity, (2) disruption of executive control of selective attention, and (3) disruption of adaptive mobilization of effort. These mechanisms were validated by Matthews and Desmond with data from driving simulator studies of stress and dual-task performance. Stress was investigated both through the experimental manipulation of certain environmental variables and the through measurement of individual differences in stress vulnerability. Variables that accentuate detrimental effects of stress include older age, inexperience at the task, and poor attentional skills. The results clearly support the role of attentional

resource allocation as the major process mediating stress effects on performance. The major limiting variable that is most clearly subject to the influence of training is inexperience. Indeed, providing experience with the task and the stressors that occur in it override the influence of age and attentional skills. These data have been taken to support the use of over-training as a countermeasure to stress.

A constraint. Hancock and Warm (1989) point out an important constraint that a general theory of stress and cognition will have to accommodate, namely, that various sources of stress from the environment don't all impact performance in the same way. Conversely, the same stressor might be reacted to in different ways by different performers. Hancock and Warm examine, in particular, the differing effects on sustained attention of acoustic stress or noise in contrast to the performance patterns that emerge from the influence of heat stress. They note that the task itself, in this case vigilance, can be its own source of stress, and that an integrated view of stress and performance must consider the task as a primary influence in the generation of stress. This assertion is consistent with the role assigned to tasks in Hammond's theory (2000). Any theory of stress must accommodate these multiple source of stress and their potentially non-additive effects of performance.

Conclusions

There is no shortage of theories about stress and it is impossible to review them all here. Fortunately, there are a few common themes among these theories and this fact provides a way to categorize theoretical ideas. Some theories emphasize the biological consequences of stress, treating behavior as a by-product of biological processes. Examples include automatic neurological and/or hormonal changes that are triggered by an event. Others focus on the behavioral consequences of stress and on cognitions that mediate the stress/behavior relationship, including importantly how the "stressful" event is appraised by the organism. In general, theories account for stress effects on cognition and on human performance in terms of multiples of processes. These processes include, but are not limited to: arousal or activation (stress intensity is directly and linearly related to arousal level), resource allocation (stress controls the distribution of mainly attentional resources across points of environmental and internal input and can overload attentional capacity), and plans or strategies. Theories differ in their assumptions

about these processes. Some attribute little or no role to consciousness or awareness, asserting that stress effects are direct, automatic, and intuitive. Others assign major performance control functions to plans, appraisals, analyses, and other cognitive phenomena. No theory that we have reviewed completely elucidates the stress process, and it is only reasonable to expect further attempts at theoretical explication is the future.

<p style="text-align:center">Arousal and Performance.</p>

Arousal, alertness, and activation are terms used in the psychological literature more or less synonymously to describe a particular state of the organism. Like any state, arousal is capable of variation in time. As an organism becomes more aroused, it likewise becomes more alert and more highly active, at least up to a point. Using a circadian analogy, sleep or initial wakening lies at the low end of the arousal continuum. The stimulation or sensory experiences attendant on waking enhances arousal level, and arousal level grows as daily events transpire. Generally people experience the highest normal levels of arousal around mid-day, although meals can cause transitory decreases and unanticipated events can cause transitory increases or decreases in arousal during the day. Arousal levels decrease with prolonged work and attendant fatigue.   The onset of darkness is associated with a return to resting levels of arousal as an individual prepares for sleep (see, e.g., Neri et al., 2002).

Human performance in nearly all situations tends to be correlated with arousal, improving up to a point as arousal level increases and falling off as arousal decreases diurnally. But there are, of course, many qualifications on this general rule. For example, arousal level can become too high for the task at hand. When a person is over-aroused, performance will deteriorate. Moreover, simple tasks like vigilance, time estimation, or the execution of a single well-practiced manual response are performed optimally under relatively high arousal levels, whereas complicated tasks such as those involving a sophisticated level of mental calculation are performed optimally under relatively low levels of arousal. Thus, it has been known for some time that modestly increasing a person's level of arousal, e.g., by introducing the threat of a painful stimulus, facilitates performance on a

simple task like time estimation (e.g., Falk & Bindra, 1954), but can hinder performance on more complicated tasks like public speaking or mental arithmetic (see Giesbrecht, Arnett, Vela, & Bristow, 1993; Lovallo, 1997).

The correlation between arousal and performance is so ubiquitous that it has come to be accepted as a law in psychology – the Yerkes-Dodson (Y-D) law, named for its putative discoverers (Yerkes & Dodson, 1908). The law takes the form of an inverted U-shaped relationship between performance and arousal. Performance on any task is best at some mid-level of arousal, falling off as arousal becomes too low or too high. The specific level of arousal that is optimal for performance differs among tasks, tending to decrease as task difficulty increases. The lawful status of this relationship was solidified by Donald Hebb in his oft-cited presidential address to the American Psychological Association (Hebb, 1955). Despite the intuitive reasonableness of this relationship and the vast amount of empirical support for it, there has been some skepticism. Hancock (2002), for example, pointed out that the Y-D law borders on the tautological, given that the result it expresses could hardly be otherwise. That is, performance in any task is bound to be poorer when the performer is under- or over-aroused. Some mid-level optimum follows necessarily. This controversy is irrelevant to present purposes, however, because we interested only in the descriptive feature of the Y-D "law."

Motivation and Arousal

Arousal might affect performance simply by activating response systems. An aroused organism is an organism that is ready to respond. Whether the activated response systems are relevant or correct for the task or irrelevant or incorrect determines whether arousal facilitates or impedes task performance. An alternative theory (see Lovallo, 1997) links arousal to motivation. The more aroused the organism is, the more it is motivated to perform well. Such a theory accounts easily for the initial upward leg of the Y-D law but requires interference or inhibitory processes to account for the possibility that an organism can be "too motivated" to perform well. Among the models that have been suggested are those

that invoke activation of competing responses at higher levels of motivation (Lovallo, 1997). Even though there might be a strong link between arousal and motivation, there is plenty of evidence that these are separable concepts. For example, Dyregrov, Solomon, and Fredrik (2000) have shown that performers can counteract the potentially degrading effects of supra-optimal levels of arousal by extra effort. Making an extra effort is surely a matter of motivation, which means that, in this example, motivation competes with arousal for control of behavior. Countervailing influences imply unique and separable motivational and arousal processes.

Stress and Arousal

Stress effects on performance are, in part and to some extent, mediated by arousal. Like arousal itself, stress can have either beneficial or degrading effects on performance, depending on the intensity of the stressor, the momentary level of arousal when the stressor occurs, the nature of the task to be performed under stress, the skill of the performer, and other variables. Light stress introduced while the participant is at some sub-optimal level of arousal has been shown to facilitate performance (e.g., Bourne, 1954; Falk & Bindra, 1954: Meyer, 1953; Spielberger, 1966, 1972). But one unique and important feature of stress is that it can induce high levels of arousal that are rarely seen in normal circumstances. Thus, often, stressors induce levels of arousal beyond optimal for performance in any task, and as a consequence, performance is degraded. Modest levels of supra-optimal stress can be counteracted by the performer by increased effort, resource mobilization, or straining (e.g., Dyregrov, Solomon, & Fredrik, 2000; Gaillard, 1993; Gaillard & Wientjes, 1994; Hocket, 1997; Matthew, Sparkes, & Bygrave, 1996). Razmjou (1996; see also Razmjou & Kjellberg, 1992) claims that resource mobilization involves deliberate processes, basically strategies for controlling effort, that allow the performer to adapt to the source of stress or arousal and to task demands. According to Hockey (1997), successful performance in any task requires the operation of a control mechanism, which allocates resources dynamically. Performance may be protected under stress by the recruitment of previously

untapped resources, but only at the expense of increased subjective effort, and other behavioral and physiological costs. Of course, performance stability can be achieved by reducing goals, without further costs.
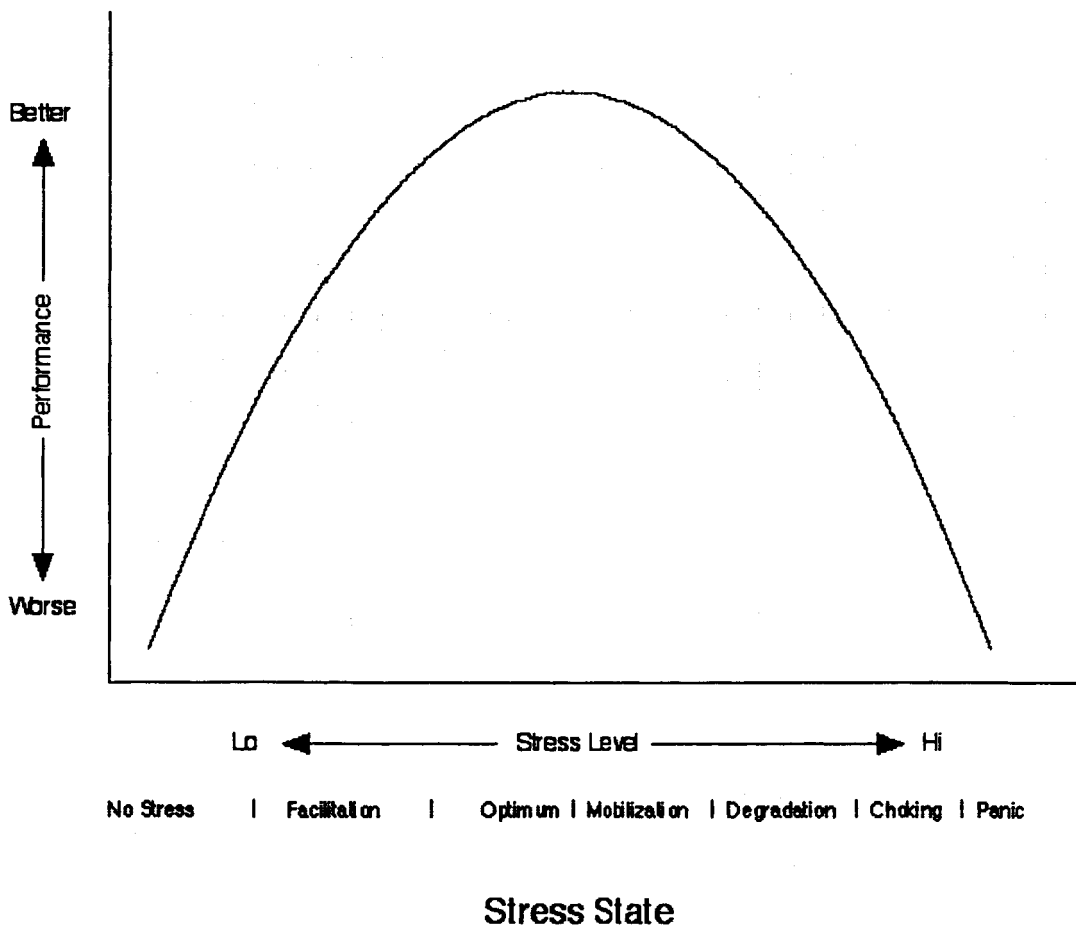
At some high level, however, stress will degrade performance. Under the press of an emergency, close examination by others, time urgency, threat of bodily harm, or other strong stressors, people often falter. Performance degrades, or worse fails. At the extremes of stress, a performer might "choke" or "panic."

Stress States: Qualitative Effects of Stress

Quantitatively, stress effects on performance follow the inverted U-shaped relationship (the Y-D law). Although there is considerable evidence in support of such a relationship, the Y-D law is not the whole story and has limited explanatory value for a variety of reasons (e.g., Hancock, 2002). For one thing, not all empirical evidence is consistent with a U-shaped function of performance across levels of arousal (Westman & Eden, 1996). Secondly, as Hockey (1983) and Hancock and Warm (1989) argued, every stressor produces its own unique pattern of effects on cognition and performance, making it unlikely to find an adequate all-encompassing principle or theory. Further different stressors can interact, often producing nonadditive effects on performance (e.g., Hygge & Knez, 2001). Evans, Allen, Tafalla, and O'Meara (1996) examined the interactive effects of multiple, sequential stressors on cognitive performance and psycho-physiological indices. Subjects engaged in a relaxing or a highly stressful activity followed immediately by performance of a task under quiet or noisy conditions. Results indicated that the negative effects of noise on both concurrent and aftereffect performance and on BP were exacerbated by prior exposure to either a lab stressor (making a speech) or to a naturalistic stressor (college final examination). Thirdly, the Y-D law relates only to arousal or system activation and not to other processes such as interference and resource demands that might also be influenced by stress. Finally, and perhaps most importantly, Y-D law relates exclusively to simple quantitative measures of goodness of performance, e.g., speed or accuracy of response.

It is clear that stress creates qualitative changes in the organism and its performance, above and beyond those captured by the Y-D law. For example, at some point, stress increments begin to degrade performance. Initial degradation is graceful, that is, small and gradual reductions in performance as stress increases. In extreme circumstances, the degradation in performance can be catastrophic, with a stress increment causing a complete system failure (Norman & Bobrow, 1975, 1976). Different stressors and different levels of stress act upon cognitive functions through different intervening states. There is need in a complete account to develop a descriptive or explanatory system that reflects these qualitatively different states.

We suggest that the concept of Stress State will help to elucidate the various

Stress State

ways in which stressful circumstances and feelings of stress influence human performance. The Stress State figure shown above serves as a useful guide to these effects. As previously noted, stress at low levels creates a state of facilitation. Chappelow (1989) was able to show in an analysis of aircrew errors that cognitive failures are often associated as much with under-arousal as they are with over-arousal. He found that performance actually improved with a little stress in the environment. At some point, stress for a given task and individual reaches an optimal state or level. Performance can be maintained at supra-optimal levels of stress if the performer can summon a higher motivational state, sometimes called a state of strain or mobilization. Mobilization of mental effort plays a prominent role in Kahneman's classical analysis of attention (Kahneman, 1973) and has received empirica support in research by Doerner and Pfeifer (1993) and by Hockey (1997). But, as stress increases even further, performance will eventually enter a state of degradation, and the performer will find him or herself less capable of adequate responding. Performance degrades, but in a relatively graceful manner (Norman & Bobrow, 1975). Extreme levels of stress produce more than simple or graceful degradation in performance. Eventually, the effects of stress can become catastrophic. A experimental example of catastrophic performance degradation with stress, resulting in a choking or panic state, can be found in Lehner et al. (1997), These researchers reported that, with extreme time pressure, subjects stopped using decision making procedures they were instructed to use and reverted to more familiar, more intuitive procedures, even though these procedures resulted in inferior performance. These qualitatively unique stress states are not captured by the Y-D law.

It is important to distinguish between choking and panicking, two extreme kinds of performance degradation resulting from stress. Before elaborating on this distinction, consider the following. When you first learn how to do a particular task, like drive an automobile or play tennis, you think through each step in a deliberate and conscious manner. You learn the task explicitly and your representation of the task lies in an array of explicit memories. But, as you train more and improve on task, responses become more automatic and come to require

less and less thought or attention. Performance becomes more fluid and skillful and is often conscious only in retrospect. The learning at this point achieves an implicit status and the representation of learned skill resides in implicit memory. What you know about any task you have learned and practiced typically has representation in both an implicit and an explicit memory system.

Choking is a form of performance degradation that involves an unintentional transition from well-learned, highly practiced, essentially automatic action to a more time consuming, controlled form of responding. This is a transition that changes the basis of responding from an implicit to the explicit memory system. The consequence of this transition is often inferior, or at least slower performance. Stress sometimes induces this transition, and that is what is meant by "choking under pressure." When you revert to thinking about each step required by a familiar task, you lose your fluidity. You begin to perform slowly and cautiously, much as you did when just starting out to learn the task. You become a beginner once again and often perform like one, relying on memories that often have not been used in quite awhile. You are "overthinking" the situation. In sports, this is what coaches mean when they use the stock phrase "paralysis by analysis." A player or the team fails because of over-analyzing the situation, rather than simply reacting.

In one of a very few laboratory studies of choking, Beilock and Carr (2001) investigated the performance of golfers. One group of participants was trained to putt a golf ball with a video camera set up in front of them, under the instruction that professional golfers would review and critique the tapes. This condition was designed to adapt golfers to being in the spotlight, raising their self-consciousness and increasing their attention to their own performance under scrutiny. A second group was trained while listening simultaneously to a list of recorded words, under the instruction to repeat the word "cognition" whenever they heard it. This condition was intended to adapt golfers to being distracted while trying to putt. A third group was trained under quiet, nondistracting conditions.

After extensive practice designed to develop a high level of putting skill, participants took a test under both low- and high-pressure conditions. The idea was to determine whether training under distracting or self-focus conditions would improve golfers' ability to perform better under pressure than normal training conditions. In other words, if you focus less than you normally would on the task at hand, which might happen when distractions are present, or if you focus more on the task, which might happen with greater self-awareness, does your performance under pressure suffer? In the low pressure test (no secondary task, no video camera, no audience), all three training groups performed equally well. In the high pressure test, in which a significant amount of money was contingent of excellent performance, the normal and the distraction training groups were significantly inferior to the self-monitoring group and performed worse than they had during training. The self-monitoring group actually performed better on the test than they had during training.

People under pressure are more stressed, anxious, and aroused and more self-conscious about their performance. Consequently, they try to exert greater conscious control over their actions, rather than allowing the skill they had acquired to guide their performance implicitly. There are numerous examples of choking due to heightened self-consciousness or other stressors in the sports literature and folklore, e.g., Greg Norman's collapse in the final round of the Masters' Golf Tournament in 1996 or Jana Novatna's last set loss to Steffi Graf at Wimbeldon in 1993. Beilock and Carr (2001; see also Beilock, Carr, MacMahon, & Starkes, 2002) argue that training in an environment in which one is forced to attend to performance from the outset can immunize the performer against the negative effects of pressure. Golfers in the self-monitoring group were protected from choking because, during training, they had adapted to the impact of conscious self-awareness and were able, unlike participants in the other two groups, to rely on implicit procedural memories to guide their performance. They were better able to "go with the flow," undeterred by extraneous stressors. Without such training, choking is a possible consequence of intense social, competitive, or other pressures.

Panic is a different stress state, and typically results in a more severe form of performance degradation than choking. When panic occurs, behavior becomes primitive; if the person thinks at all, it is maladaptive automatic thinking (Katz & Epstein, 1991). Panic is not just a matter of reverting to behaviors that had been learned earlier or to memory representations in an explicit form. Panic is characterized by an even more rudimentary, instinctive kind of behavior aimed at survival. Rather than "overthinking" the situation, a panicked person stops thinking altogether and is inclined to react in the most basic way to get out of the situation or to escape the stressor. Stress appears to cause explicit memories to become unavailable or irretrievable. In a panic state, short-term memory seems to cease functioning. The person just freezes, that is, fails to respond, responds in an automatic but unskilled way, or reverts to primal instincts . Moreover, high arousal, as under stress, results in perceptual narrowing (Easterbrook, 1959). The range of cues or sources of informational input that an organism might use to escape the situation is reduced. The panicked individual focuses, indeed often obsesses on one aspect of the environment, usually to the neglect of information that could eliminate the stressful condition. The consequence is that, even though the goal is survival, performance is functionally maladaptive (Katz, & Epstein, 1991). To use another bit of sports jargon, coaches have been known to refer to a state of panic as "brain lock." The cognitive performance system is locked down.

Conditions of panic are virtually impossible to create in the cognitive psychology laboratory. Thus, most of what we know about panic under stress comes for case histories and self-reports. Good examples come from SCUBA diving and sky diving. Skydivers have two parachutes and are trained such that, if the primary chute fails to open, they should immediately pull the cord on the secondary chute. There have been reported accidents resulting from a failure to do so. People have been found dead or injured on the ground still clutching the cord to the primary chute. Apparently, these victims pulled the cord for the primary chute and, when it failed to open, panicked, continued to tug, but never thought

about the secondary parachute. Other poignant examples from piloting can be found in Langewiesche (1998).

Panic is clearly a state to avoid, if one is to escape an emergency situation. The question is, can we develop training routines that minimize the likelihood of panic in situations that are susceptible to emergencies. On the basic research side, we need to develop experimental paradigms, building on the work of Beilock and Carr, that permit the establishment of choking and panic states under laboratory conditions. There seems to be little evidence of that possibility at this writing.

<u>Conclusions</u>

There is a close relationship between stress and arousal. Stressful events are arousing, causing attendant changes in states of the organism, in cognitive processes, and in performance. Of greatest relevance to behavior in emergencies are the stress states of (1) <u>strain or mobilization</u>, wherein the person recruits untapped resources to maintain performance levels when arousal is supra-optimal, (2) <u>degradation</u>, wherein mobilization fails and performance suffers but only gradually, (3) <u>choking</u>, wherein performance might fail as the organism over-thinks the tasks at hand, and (4) <u>panic</u>, wherein performance reverts to non-cognitive primitive modes of behavior. Research has established the basic parameters of these states, but little is known in detail about situations and individual differences that are conducive to them or about the cognitive difference among them. This fertile ground for future empirical research.

Appraisal

Lazarus (1990; see also Lazarus & Folkman, 1984) developed a comprehensive cognitive model of behavior in response to stress. That model is based on the fundamental assumption that a potentially stressful life episode does not actually create stress unless it is appraised as threatening. That is, the ways people think about situations determine how they respond emotionally and how they cope with those situations.

As reasonable as it might sound, many of Lazarus's postulates have received little empirical attention, and some of the existing research has yielded

contradictory findings. For example, Zakowski, Hall, Cousino-Klein, and Baum (2001) conducted a longitudinal study to clarify the associations among feelings of control, appraisal, coping, and stress. Lazarus's theory postulates that coping strategies tend to match the level of appraised controllability of the stressor (matching hypothesis). Recall that Hammond's (2000) theory contains a related postulate to the effect that a match between strategy and task renders a situation non-stressful. An alternative to Lazarus's expectation is the main-effects hypothesis, which states that problem-focused coping is generally more effective in reducing distress regardless of appraisal. These hypotheses were tested by Zakowski et al. with 72 adults who completed questionnaires on coping, control, and appraisal. Stress was assessed using both a self-report and a behavioral measure at two different times approximately 2 months apart. The matching hypothesis was consistent with both self-report and behavioral measures of stress, giving some of the strongest evidence for appraisal theory yet reported.

Mathews and MacLeod (2002) argued that appraisals can be readily induced or changed by laboratory manipulations. Induced biases (or appraisals) affect felt anxiety when they influence how emotionally significant information is encoded by a participant. Biases and appraisals affect vulnerability to anxiety via their influence on how stimuli are processed or interpreted. Mathews and MacLeod argued that it is relatively easy to set someone up for an anxiety attack by giving him or her the right orientation toward or appraisal of up-coming events or information.

The cognitive appraisal model also predicts that a person's interpretation of an event affects the intensity of his or her reaction to it. A study by Zohar and Brandt (2002) shows that, in cases involving a variety of possible stressful factors, the most salient stressor governs appraisal, not the summation of stressors or any other interaction of stressors. The condition perceived to be most important captures attention and takes control of how the person appraises and subsequently responds to the situation.

Anticipation of a stressful event, such as a parachute jump or piloting a plane, often includes a great deal of uncertainty. There might be a large number of unknowns, and emotions can range from extreme negative (worry, fear, anxiety) to positive (hope, eagerness, exhilaration). Skinner and Brewer (2002) studied the emotional feelings experienced during this anticipation period by students preparing for a college examination and certain other stressful events, particularly as they relate to the participants' appraisals of the event as a challenge or a threat. Compared to threat appraisals, challenge appraisals were associated with better emotion-coping styles, more positive emotional feelings, and greater confidence about performance. Moreover, participants who viewed the up-coming event as a challenge performed significantly better on that task. Because coping styles, appraisals, and emotional feelings were established in advance of the event itself, they all appear to have significant roles in mediating or determining performance.

Ennis, Kelly, Wingo, and Lambert (2001) hypothesize that subjects' appraisal of a task or situation causes differential elicitation of neuro-endocrine activity. They determined that, if a subject sees an academic exam as a threat, sympathetic neuro-endocrine activity (measured in urine) increases before the event, relative to subjects who see the exam as a challenge. During or after the exam, activation drops and there is no difference between the threat and challenge groups in posttest measures. Overall, Ennis et al. found a positive correlation between self-reports of anxiety and adrenomedullary activity. The authors conclude, consistent with Lazarus's model, that appraisal mediates not only behavior but also certain biological components of the human stress response.

Rohrmann, Hennig, and Netter (1999) used a different approach, but came basically to the same conclusion as Ennis et al. Rohrmann et al. demonstrated that psycho-biological reactions to the stress of public speaking can be manipulated by giving participants pre-speech information regarding how to appraise the state of their body. During an anticipation period before a speech, subjects were given either no information (in the control condition), were given information to the effect that they were psychologically aroused and nervous (in an arousal

condition), or that they were psychologically calm and relaxed (in a reassurance condition). Heart rate (HR), BP, cortisol levels, and electrodermal responses were highest in the reassurance condition and lowest in the control condition. Felt emotional stress reactions, in contrast, were highest in the arousal condition and lowest in the reassurance condition. Somatic arousal was greater than felt emotion in the reassurance condition whereas felt emotion was higher than somatic arousal in the arousal condition. The authors concluded that different appraisals and consequently different coping styles were induced by pre-training. The arousal condition induced a coping style that sensitizes the subject to the state of his or her body; in contrast the reassurance condition induced a more cognitive style of stress reduction. In any case, establishing a way of appraising a potentially stressful situation mediated psycho-biological reactions to and performance during the event.

Prior to a film depicting three serious factory accidents, Danboy and Goldstein (1990) instructed some subjects about how to take and maintain a detached attitude – intellectualizing instructions – while others were merely told about the content of the up-coming film. Intellectualizing subjects demonstrated less self-reported stress and lower galvanic skin responses (GSRs). All subjects were less accurate on a memory test for accident related as opposed to non-accident related aspects of the film. Thus, how you appraise the film or the events it depicts controls to some degree the emotion the film provokes, a result which is consistent with Ennis, et al. (2001) and Rohrmann, et al. (1999), although in a different context.

Larsson (1989) reported a study of the performance of Swedish military personnel on an artillery simulator, under conditions of calm, noise, and noise plus 27 hrs sleep deprivation. Apprising the task as a challenge was associated with positive coping and better performance, relative to a threat appraisal, under all conditions. But performance degraded with increased stress and negative coping increased with increased stress. Those subjects who were high in achievement motivation were more likely than those subjects who were low in achievement

motivation to appraise noise and sleep deprivation as challenging and to use coping strategies that were positive and action oriented. Positive coping strategies tended to counteract the adverse effects of stress. Similar results were reported with college students by Wallbott and Scherer (1991).

Conclusions

There is a fair amount of agreement in the current literature on appraisal and stress. First, cognitive appraisals play a significant mediating role in biological reactions to stress. Second, performance outcomes depend in part on whether the subject appraises the situation as a challenge or a threat. Third, appraisals tie into coping styles such that challenges are associated with positive and more successful coping styles whereas threats are associated with negative styles. But the picture is not completely clear. It might be that, in all the experimental situations explored to date, more competent people are more likely to view any situations as a challenge rather than a threat. If this is the case, then better coping and better performance naturally follow from challenge appraisals. Because, as yet, no one has been able to create a way of separating conceptually appraisal from competence, we are left with basically a correlational result and without a clear picture of the cause-effect relationships that are involved.

Attention and Perception

It is clear that stress, especially acute stress, has important effects on attention and perception. But the effects are quite irregular, and depend in serious ways on the qualitative features of the stressor. Different stressors have different effects on performance. One stressor might cause shifts in attention or a failure to inhibit irrelevant stimuli, while another stressor causes a lapse of attention or attentional narrowing in the same task.

Inhibition and Attention

Given that the effects of stress on attention can be unpredictable, still there are some results that are general, systematic, and reliable. One example is the latent inhibition (LI) effect. Pre-exposure to a stimulus reduces the utilization and the learning of that stimulus on some later occasion. This LI phenomenon is

typically attributed to a reduction in attention to stimuli caused by their pre-exposure in another task. When stress is present in the learning or test phase, however, latent inhibition is reduced or eliminated. Attention to the stimulus is not affected by pre-exposure and learning involving the pre-exposed stimulus is as good as if the stimulus was novel. Stress was induced in one experiment (Braunstein-Bercovitz, Dimentman-Ashkenazi, & Lubow, 2001) by threats to self-esteem in a difficult number series completion test said to be related to intelligence. In a second case studied by the same authors, the LI task was described as a part of the selection process to job seekers. LI was attenuated in both experiments in high as opposed to low stressed subjects. Thus the results show that stress impairs the inhibition of irrelevant pre-exposed stimuli.

Is proneness to anxiety associated with impaired inhibitory processing? Participants in a series of experiments reported by Wood, Mathews, and Dalgleish (2001) made speeded decisions which required inhibition of the meaning (threatening or neutral) of ambiguous words. Under normal conditions, they found that anxious and non-anxious participants perform equally well in this task. However, when a mental load was induced to reduce controlled processing, anxious subjects did not inhibit word meaning as well as non-anxious subjects. In a final experiment, attenuation of inhibition was demonstrated even without mental load in subjects who had recently experienced a traumatic event.

Keinan, Friedland, Kahneman, and Roth (1999) reported similar stress effects with both college students and navy personnel using a variety of cognitive tasks, including arithmetic, estimation, number series, and analogies. In the number series and analogies tasks, both of which required the inhibition of competing responses, but not in the other tasks, performance was poorer in the high than in the low stress condition. These authors concluded that stress **heightens the difficulty of suppressing or filtering out competing responses.**

Mogg, Bradley, and Hallowell (1994) tested high and low trait anxious students for attentional bias to threat stimuli (words) under no stress, laboratory-

induced stress, and natural examination-induced stress. High anxious subject showed an attentional bias toward threat words, but only when those words were presented for long duration, without a mask, and under examination threat. Anxiety sensitized the subject to threat mainly when the induced anxiety is somewhat protracted.

Measured levels of stress hormones are consistent with the above-demonstrated effects of stress on inhibitory processes. Skosnik, Chatterton, Swisher, and Park (2000) induced mild stress into the verbal priming paradigm using a video game. Stress reduced negative priming, a measure of inhibition processes, and also increased salivary cortisol and alpha-amylase (a correlate of norepinephrine).

So, both chronic anxiety, as in trait anxious subjects, or acute anxiety, as in trauma, is associated with a general deficit in inhibition of attention, and is best revealed when limitations are placed on controlled processing, forcing subjects to rely more heavily on automatic reactions. Behavioral and physiological measures are consistent with changes induced by stress on inhibitory processes. These results imply that, in a natural emergency, when stress is high, there is need to be concerned about an operator's ability to focus on the relevant information in the task at hand and to inhibit irrelevant sources of input.

Perception and Cue Utilization

Based on a review of the early literature on arousal and attention, Easterbrook (1959) concluded that stress, anxiety, or high arousal can narrow the range of environmental cues utilized, shrinking one' effective perceptual space. This idea has been expanded by Cowan (1999) in a theoretical analysis of working memory. Among other things, Cowan draws a sharp distinction between attentional processes, which in his view are basically capacity-limited, and working memory, (the activated portion of long-term memory in his theory), which is basically time-limited. Thus, consistent with Easterbrook, Cowan predicts that

the effects of stress on attention are to limit its scope or content. People attend to and process less perceptually-available information when they are stressed. In contrast, the effects of stress on memory are to limit its time extension. Such an expectation is consistent with the memory constriction hypothesis that we develop in this report. Since Easterbrook's publication, there have been numerous demonstrations of an attentional deficit under stress, in and outside of the laboratory. For example, Ozel (2001) found that time pressure and the stress created by the threat of fire affects how people process information provided to them about the right route to take to escape. Slight stress was beneficial to escape performance, but higher levels of stress narrowed the range of environmental cues attended to or processed and increased the use of negative coping styles by participants. Escape performance suffered as a consequence.

Vigilance

Performance in a vigilance task, which requires the detection of infrequent stimuli, degrades in time, a phenomenon known at the vigilance decrement (Mackworth, 1950). Galinsky, Rosa, Warm, and Dember (1993) observed that restlessness and subjective fatigue, both indices of stress, increased dramatically across a 50-min watch in a vigilance task in which sensory modality of signals (audition and vision) and the background event rate (5 and 40 events/min) were varied. Stress effects were most notable in the case of visual monitoring but were unrelated to variations in event rate. Thus, the stress of sustained attention seems to be identified more specifically with the sensory modality of signals than with the event rate context in which they appear. Temple, Warm, Dember, Jones, LaGrange, and Matthews (2000) observed that 30 mins or more of sustained vigilance produces not only a performance decrement, but also increases in felt workload and stress. Stimulant drugs, like amphetamine sulphate or caffeine, extraneous auditory stimuli, and other arousing agents should enhance vigilance and counteract the deterioration in vigilance performance that occurs with the passage of time. Temple et al. (2000) found evidence that ingestion of caffeine

during the task improved vigilance and signal detection but did not reduce task-induced stress.

Lavine, Sibert, Gokturk, and Dickens (2002) examined concurrent eye movements and human performance during a vigilance task designed to require frequent visual scanning. Stimuli were 4 digits in a rectangular array, changed at an event rate of 4 s for a task duration of 30 min. Participants were asked to respond to specific, infrequent signal arrays by bar press, under both 50 dBA white noise and 90 dBA intermittent and unpredictable sound-burst conditions (SBC). With time-on-task, subjective fatigue ratings increased, the total duration of fixations on target digits decreased, number of fixations decreased, and fixations were further from target digits in both conditions. Thus, the usual vigilance performance decrement was replicated. Fixation duration did not change significantly with time or condition. Off-target visual scan-paths were less frequently followed by hits than were on-target scan-paths in both conditions. With the SBC, fixations were closer to target digits and hit rates increased, suggesting that background stimuli with a potential alerting function can help to offset the vigilance decrement.

Conclusions

Both chronic anxiety, as in trait anxious subjects, or acute anxiety, as in trauma, produce a general deficit in a person's ability to inhibit irrelevant stimuli. The effect is most clearly revealed when limitations are placed on controlled processing, forcing subjects to rely more heavily on automatic reactions. These results imply that, in a natural emergency, when stress is high, there is need to be concerned about an operator's ability to focus on the relevant information in the task at hand and to inhibit irrelevant sources of input. This effect of stress on inhibitory processes is similar to and likely related to Easterbrook's finding that the range of cues perceived and attended to shrinks under stress or high arousal. Other evidence shows that the ingestion of stimulants can be effective in offsetting the vigilance decrement as can the aperiodic occurrence of irrelevant or background stimuli, if they have some degree of alerting function.

Memory

. As we have noted earlier, cognitive psychology is currently concerned with a variety of forms of memory. One important distinction applies to the temporal character of information retrieved from memory. This distinction is based on a continuum from the remote past – retrospective long term memory – to the present or near present – short term memory and immediate or working memory – to the future – prospective memory. Long-term memory is theoretically a repository for facts and skills acquired in the past. Short term and immediate memory holds facts and skills that are currently at the focus of attention. Prospective memory contains reminders of actions to be executed at some future time and place. The important variables influencing memory might not the same in all three cases. One variable that seems likely to be influential is stress.

Stress effects have been studied in the context of various forms of memory, although the experimental data available are surprisingly few. There are no data comparing different forms of memory for their relative susceptibility to stress. The evidence that is available seems to suggest that stress, in general (including stress arising in emergency situations), causes the operator to focus on the here-and-now, with consequent potential degradation of retrospective and prospective memory performance. The results are consistent with a memory constriction or tunneling

hypothesis to the effect that the time span from which knowledge can easily be retrieved and used in a given context shrinks as stress level increases. Neglect of facts or procedures in long term memory, and failure to execute required behaviors at appointed future times is a major reason for performance errors or failures in emergencies. Although memory tunneling has been observed in the retrieval of autobiographical events (Berntsen, 2002), empirical evidence to support this broad stress/memory hypothesis is weak. The hypothesis could, however, serve a framework for future research efforts.

General Stress Effects on Memory.

As we have shown in other sections of this report, a variety of stressful conditions impede a variety of memory measures. For example, Gomes, Martinho-Pimenta, and Castelo-Branco (1999) showed a significant impact of stressful noise on immediate verbal memory. Fowler, Prlic, and Brabant, (1994) reported a similar effect of hypoxia on the executive function of working memory. Mandler (1979) was one of the first cognitive psychologists to speculate theoretically about the effects of stress on memory. Stress produces noise in the cognitive system, according to Mandler, which competes with task demands for limited cognitive, that is, conscious resources. Recall that a similar proposition about noise in the cognitive system, generated by stress, was made by Van Gemmert and Van Galen (1997). Thus, in Mandler's theory, those memory processes that rely on conscious elaboration of input and representations, namely explicit memory processes, should be especially degraded by stress. To date, there has been no clear test of this hypothesis. It is not inconsistent, however, with the memory constriction (tunneling) hypothesis describe earlier, in the sense that focusing on the here and now necessarily requires explicit memory while longer term recall and prospective recall might not.

As we shall discuss in detail later, Van Overschelde and Healy (2001) have shown empirically that one mechanism for coping with and reducing the stress that information overload engenders is to provide connections between new facts to be

learned under stress and an existing knowledge base. The general principle is that the acquisition and retention of new, factual information is facilitated whenever that new information can be linked to existing knowledge. The mechanism underlying this strategic-use-of-knowledge principle is based on the provision of a retrieval strategy supported by factual information that already exists in long-term memory. This idea is an extension of the theory of long-term working memory (Ericsson & Kintsch, 1995), which has been used, for example, to account for text comprehension and for expert-level performance in memory-span tasks. This is still another hypothesis that should be testable empirically, although it has not been examined in the literature to our knowledge.

Another approach to the role of working memory in the explanation of stress effects is represented by the work of Ashcraft (2002; see also Ashcraft & Kirk, 2001). People with high math anxiety have a reduced working memory capacity according to Ashcraft. Because working memory is required by many arithmetic and mathematical tasks, math anxious subjects perform more poorly on these tasks than low anxious subjects. This leads to the prediction that, if working memory can be limited artificially in non-anxious subjects, their performance on calculation tasks should similarly be adversely affected. By introducing a concurrent task with working memory demands or by stretching working memory by primary task demands, Ashcraft was able to show effects on performance similar to those observed in high math anxious subjects. Ashcraft's conclusion is that stress exerts its effects primarily by reducing a person's working memory capacity. Such a result, if replicable, might be inconsistent with the memory constriction hypothesis, described above, in the sense that memory constriction implies a greater effect of stress on retrospective and prospective memory than on working memory. Studies comparing various forms of memory under stress are needed to decide between these hypotheses. Any task that requires explicit learning and/or memory processes should be especially liable to stress effects, according to Ashcraft.

Conclusions similar to those of Ashcraft have been reached by Eysenck (1992, 1997; see also Eysenck & Calvo, 1992). Moreover, in a recent review of

research on working memory, Miyake and Shah (1999) identified emotion, stress, and especially anxiety as a major modulating factor of working memory capacity. They suggest that, in various ways, stress limits the time scope of memory. But, after searching the literature, they concluded that insufficient empirical data have been collected on the problem and recommended further research to identify what aspects of working memory (e.g., maintenance, executive control, content) are influenced by anxiety and other emotional factors. Why should working memory capacity be reduced under stress? Matthews (1996) argues that "worries," daily hassles, and/or intrusive thoughts tend to occupy more space in working memory among high anxious than among low anxious subjects, limiting the available working memory space in high anxious subjects for the calculations that their primary task requires (see also Dudke & Stoebber, 2001). There is some evidence that a stressful event, itself, can cause lingering intrusive thoughts (see below), but little data at present to support Matthews's "worries" hypothesis.

A caution. Studies of stress and memory must take account of state and context dependency effects. That is, it has routinely been shown that performance in a retention test is better if the state of the subject and/or the context in which the test is administered are the same as the state and context of original learning. Although stress might exert adverse effects on both encoding and retrieval processes, there is some possibility that changing the stress state of the organism between the times of learning and retention, from stress to no stress or from no stress to stress, will have its own adverse consequences. But, other things being equal, recall performance will be better if tested under the same state, stress or non-stress, as present during encoding. Lang, Craske, Brown, and Ghaneian, (2001) demonstrated this phenomenon in a word recall task using induced states of both fear and relaxation. But, most studies of stress and memory in the current literature ignore these dependencies, usually testing the subjects' memory under stress for information or skill acquired under non-stressful circumstances. This is a serious limitation on the usefulness of the current stress/memory literature, and must be corrected in future work.

Memory for emotion-arousing stimuli. There is conflicting evidence in the literature regarding memory for emotionally arousing stimuli. As we noted earlier, most studies have reported that memory is better for either pleasant or unpleasant material than it is for emotionally neutral material. But there are exceptions. Further, some investigations have, reported that traumatic stimuli, like autopsy photos, can inhibit memory for simultaneously presented neutral material (see, e.g., Kramer Buckhout, Fox, Widman, et al, 1991). Whether these differential observations should be attributed to differing methods of presenting materials and measuring memory or to the degree of emotion provoked by the stimulus material is not clear at the present time.

Lang, Davis, and Ohman (2000) attempted to explicate what is special about memory for emotional information, emphasizing the neural foundations that underlie the experience and expression of fear. They proposed that unpleasant emotions depend on the activation of an evolutionarily primitive subcortical circuit, including the amygdala and the neural structures to which it projects. This motivational system mediates specific autonomic (e.g., HR change) and somatic reflexes (e.g., startle response) that originally promoted survival in dangerous conditions. These authors show how variations in the neural circuit and its outputs may separately characterize cue-specific fear (as in specific phobia) and more generalized anxiety. Emphasizing links between animal and human data, these authors focus on certain special, attentional features of emotional processing, including: (1) The automaticity of fear reactions, (2) hyper-reactivity to minimal threat-cues, and (3) evidence that the physiological responses in fear are independent of slower, deliberate language-based appraisal processes. This last difference accounts, in their view, for the special character of and better memory for emotional as contrasted with neutral information.

Cortisol and other Neuro-biological Considerations..

Cortisol is a stress hormone that readies the body to fight or for flight. Among other things, cortisol stimulates the secretion of intracellular glucose into

the blood, which allows longer and more vigorous and sustained responding. Although the mechanism is less clear, it is also known that ambient cortisol levels can affect cognition.   For example, al'Absi, Hugdahl, and Lovallo (2002) showed that participants who had a large cortisol responses, i.e., acutely elevated levels of cortisol, during mental arithmetic and public speaking tasks, performed better 30 mins later on a dichotic listening task, compared to those who had low cortisol responses. Dichotic listening requires sustained focused attention to external stimuli, and sustained attention is known to engage the executive processes of working memory. Thus, it is of great interest that working memory depends on adequate functioning of the dorsolateral prefrontal cortex (Smith & Jonides, 1999), an area richly supplied with corticosteroid receptors and corticotropin-releasing factor terminals. It has been argued that these studies imply that emotional dispositions, possibly even more than environmental circumstances, are crucial in how one responds behaviorally to stress (Kosslyn, Cacioppo, Davidson, Hugdahl, Lovallo, Spiegel, & Rose, 2002).

As noted above, there is evidence that stress has effects on both encoding of new memories and retreival of old memories. But what about memory storage, the process of holding memories after encoding for later use in retrieval tests? For several decades, the concept of modulation of storage has significantly influenced research investigating neurobiological memory mechanisms in animals. New evidence provides additional support for the view that stress hormones released during emotionally arousing situations can influence memory storage. Recent experiments have investigated the role of sympathetic adrenomedullary hormones in emotional memory in human beings, as well as the role of adrenocortical hormones, primarily in animal studies. Further, it is becoming increasingly clear that the sympathetic adrenomedullary and the pituitary adrenocortical systems interact to modulate memory storage. Other new evidence emphasizes the role of peripheral influences to the brain on emotional memory, as well as the critical contribution of the amygdaloid complex in modulation of memory by emotional arousal. For a review of this literature, see Cahill and McGaugh (1996).

Glucocorticoids (GCs), produced by the stress-responsive hypothalamic-pituitary-adrenal axis, are well recognized for their regulatory role in peripheral metabolism. But GCs are also known to regulate various brain functions, involved in human cognition (Cahill & McGaugh, 1996). Increased GC exposure in human beings at levels associated with stress has most often been found to decrease memory and learning function (see below). Evidence of these effects in adult human beings and animals has been reviewed by Hefflinger and Newcomer (2001). As an aside, these authors pointed out that less is know about cortisol and memory in children and older people than in adolescents and adults. But Cahill and McGaugh (1996) have speculated that cortisol levels can, in some circumstances, enhance memory function. Buchanan and Lovallo (2001) attempted to test this idea and to extend findings with animals to human memory performance. Following administration of cortisol or placebo, college aged participants were exposed to pictures varying in emotional arousal. Incidental memory for the pictures was assessed one week later. Results showed that elevated cortisol levels during memory encoding enhanced the long-term recall performance of emotionally arousing pictures relative to neutral pictures. It is not clear why cortisol should selectively support memory for emotion provoking stimuli. But in general the results suggest that cortisol secretion can have beneficial cognitive effects in some circumstances. Note that Buchanan and Lovallo failed to control for state dependency, which once again prevents a clear interpretation of the role of stress (or cortisol) in encoding vs. retrieval processes.

Most of the recent literature with human subjects is not consistent with the results of Buchanan and Lovallo (2001), and more in line with the adverse effects of elevanted cortisol claimed by Hefflinger and Newcomer (2001). For example, Kirschbaum, Wolf, May, Wippich, et al. (1996) reported two experiments on the association between cortisol levels and memory in healthy human adults. In the first study, subjects were exposed to the Trier Social Stress Test with a subsequent test of declarative memory performance. Results indicated a significant negative relationship between stress-induced cortisol levels and performance in the memory task. The second experiment investigated whether cortisol alone, independent of

psychological stress, would also impair memory function.   Male Ss received either 10 mg cortisol or a placebo orally. One hour later they were tested for procedural and declarative memory and spatial thinking. Subjects who received cortisol showed impaired performance in the explicit declarative memory and spatial thinking tasks although not in the implicit procedural memory task. Accordingly, their results suggest that, in healthy adults, elevated free cortisol levels may be associated with impaired explicit memory function, that is, functions that require conscious awareness and an important role for working memory, but not functions that operate automatically.

Wolf, Schommer, Hellhammer, McEwen, Kirchbaum, (2001)) reviewed epidemiological and experimental studies and found that elderly subjects are especially susceptible to memory impairing effects of elevated cortisol levels, postmenopausal women more so than elderly men. They noted further that, on the whole, little is known about gender differences in susceptibility to acute stress in young subjects.   Therefore,Wolf at al (2001) conducted a study of healthy college students who learned a word list, with recall being tested after a brief distraction task. Some of their subjects learned the list after exposure to a psychosocial stressor, while the remaining subjects served as controls. Free cortisol was determined via saliva samples taken before and 10 mins after stress. Subjects exposed to the stressor, did not show impaired memory performance per se when compared to the control group. However the size of the cortisol increase in response to the stressor was negatively correlated with the memory performance within the stressed group (i.e., subjects showing a larger cortisol response recalled fewer words than subjects showing only a small cortisol increase). Additional analysis by Wolf et al. (2001) revealed that this correlation was high in men and nonexistent in women. The data suggest that gender might modulate the association between cortisol and memory after stress.

Newcomer, Selke, Melson, Hershey, Craft, Richards, and Alderson, (1999) reported an experiment in which participants were given 1 of 2 oral hydrocortisone doses or a placebo. Paragraph recall was used as a measure of verbal declarative

memory. Results indicate that several days of exposure to cortisol at doses and plasma concentrations associated with physical and psychological stress in human beings decreases verbal declarative memory function in otherwise healthy human beings. Another related result was reported by Vedhara, Hyde, Gilchrist, Tytherleigh, and Plummer, (2000), who conducted an investigation to explore the relationship between acute changes in cortisol and memory and attention in the context of an acute naturalistic stressor, namely, examination stress in college students.   Assessments of self-reported levels of stress, salivary cortisol, short term memory, selective and divided attention, and auditory verbal working memory were conducted during a non-exam and an exam period. The results revealed that the exam period was associated with an increase in perceived levels of stress, but also a significant reduction in levels of salivary cortisol, compared with the non-exam period. This reduction in cortisol was associated with enhanced short-term memory (as measured by the total number of words recalled in a free recall task), impaired attention and an impairment in the primacy effect (a hippocampal-specific index of short term memory), but no significant effects on auditory verbal working memory.

Further confusing the picture is a study reported by Lupien, Gillin, and Hauger (1999) who measured the effects of various doses of hydrocortisone on performance in tasks assessing working and declarative memory function. During the infusion period, participants were given an item-recognition working memory task, a paired-associate declarative memory task, and a continuous performance task used to control possible concomitant effects of corticosteroids on vigilance. The results revealed significant acute degrading effects of the highest dose of hydrocortisone on working memory function, without any significant effect on declarative memory function or arousal-vigilance performance. These results suggest that working memory is more sensitive than declarative memory to the acute elevations of corticosteroids, which could explain the detrimental effects of corticosteroids on acquisition and consolidation of information, sometimes reported in the literature (Cahill & McGaugh, 1996). Taken as a whole, the

available data support the unsatisfactory conclusion that cortisol modulates cognitive processes, but in a highly selective manner

The results of Wolf et al., Vedhara et al, Newcomer et al., and Lupien et al. all appear to be inconsistent with Buchanan and Lovallo's finding of cortisol support for retrospective memory of emotion-arousing stimuli. More data will be required to reconcile this discrepancy. Of course, one possible explanation is that various researchers induced or measured cortisol levels at different points on the Yerkes-Dodson function. Thus, Buchanan and Lovallo's data might to attributable to a relatively low cortisol level in their subjects, thereby facilitating performance on the upward rise of the Y-D function, while other researchers induced or measured higher levels of cortisol, beyond the optimum on the Y-D function. More than anything else, this possibility demonstrates how slippery the issue is and how the Y-D principle can be used to explain almost any outcome. Further complicating the picture is the fact that none of these experiments took account of possible state dependency effects. Thus it remains unclear whether the effects of elevated cortisol levels, whether facilitative or adverse, are the same on encoding and retrieval processes in memory.

According to de Kloet, Oitzl, and Joëls (1999), some of the discrepancies reported in the memory literature as regards the role of corticosteroid hormones might be explained by appealing to the specific role of both mineralocorticoid and GC receptors in the various stages of information processing. Corticosteroid effects on cognition can turn from adaptive into maladaptive when actions via the two corticosteroid-receptor types are imbalanced for a prolonged period of time. But before we should accept the de Kloet et al. claim, or any other possibility that relies on biological explanation, experiments with proper control and manipulation of cortisol levels and state dependencies in encoding and retrieval will need to be conducted and reported.

Context and State Dependency involving Stress.

One of very few studies to take account of state and context dependency effects in memory was conducted by Thompson, Williams, L'Esperance, and Cornelius (2001). In the first of two experiments, experienced skydivers learned word lists prior to skydiving either in the air or on the ground and recalled them in the same context or in the other context. The second experiment was a replication of the first except that participants were shown a skydiving video in lieu of actual skydiving. Recall was poor in air-learning conditions with actual skydiving, whether learning took place in the air or on the ground. But when lists were learned on land, recall was higher in the matching context than in the mismatching context. In the skydiving video experiment, recall was higher in matching learn-recall contexts regardless of the situation in which learning occurred. It is proposed then that under extremely emotionally arousing circumstances, environmental and/or mood cues are unlikely to become encoded or linked to newly acquired information and thus cannot serve as cues to retrieval. Context and state dependency effects are real, but might be overridden when emotions are extreme. Results can be applied to understanding variations in context-dependent memory in occupations in which the worker experiences considerable emotional stress while learning or recalling new information. But the main point is that these dependency effects must to be taken into account in all future experiments purporting to study stress and memory.

Other Considerations

False memories. Payne, Nadel, Allen, Thomas, and Jacobs (2002) demonstrated that stress can enhance a person's susceptibility to false memories. In a recall task, participants' ability to distinguish words that were presented for study from critical lure words that were semantically related, but not presented for study, was selectively disrupted. This finding indicates that stress potentiates false memories. An argument was made by the authors that this effect is mediated through the impact of stress on the hippocampus and prefrontal cortex, but this

interpretation is an extreme extrapolation from the data, which contained no measurements of brain activity.

Intrusive thoughts. Not only does stress affect and often limit memory, but also memories of stressful events can provide a basis for intrusive thoughts, resulting in persistent, protracted, lingering, or chronic stress – a kind of vicious circle (Baum, Cohen, & Hall, M, 1993). Intrusive thoughts have been identified as key elements in chronic or traumatic stress and the post-traumatic stress syndrome, but many questions remain about how they operate and what causes their persistence over time. Schooler, Dougall, and Baum (1999) considered these questions, examining the impact of having intrusive thoughts that are cued by stimuli in one's environment as opposed to non-cued intrusions that seem to "come out of the blue." This research evaluated the extent to which distress accompanying intrusive thoughts shortly after a traumatic event predicts persistence of intrusions over time. Rescue workers who responded to the crash of Flight 427 were studied 4-8 weeks, and 6, 9, and 12 months after the disaster. Participants who reported crash-related thoughts that were not prompted by cues showed higher levels of distress than those reporting only cued thoughts or those reporting neither. The magnitude of distress that these non-cued thoughts caused in the first 2 months after the crash was important in predicting subsequent frequency of unwanted thoughts. Matthews (1996) has argued that intrusive thoughts and other "worries" occupy space in working memory, thus limiting performance in tasks that rely on working memory. But, at this time, no one has reported any solid evidence to support the detrimental effects of intrusive thoughts, whether cued or non-cued, on subsequent cognitive task performance.

A Memory Constriction Hypothesis

As noted earlier, one important distinction in contemporary memory research and theory applies to the temporal focus of information to be retrieved from memory and used. This distinction is based on a continuum from the remote past – retrospective long term memory – to the present or near present – short term

memory and immediate or working memory – to the future – prospective memory. The effects of important variables, including stress variables, might not be the same in all of these cases. Somewhat surprisingly, the data available on possible differences are surprisingly skimpy. Moreover, there are few systematic studies of stress on memory over a wide range of stress values. To our knowledge, there are no direct comparisons of retrospective, working, and prospective memory under stress. What evidence is available seems to suggest that stress typically causes the performer to focus on the here-and-now, with consequent degradation in retrospective and prospective memory. The results are consistent with a memory constriction or tunneling (Bernsten, 2002) hypothesis to the effect that the time span from which knowledge can easily be retrieved and used in a given context shrinks as stress level increases. Neglect of facts or procedures in long term memory, and failure to execute required behaviors at appointed future times might be a major reason for performance errors or failures in emergencies. Unfortunately, at the present time, empirical evidence to support this hypothesis is nonexistent. The hypothesis could, however, serve as a framework for future research efforts.

Conclusions

A variety of stressful conditions affect a variety of memory measures, usually but not always in an adverse way. Mandler was one of the first cognitive psychologists to theorize about these effects, attributing them to cognitive resource limitations and to stress-produced noise in the cognitive system. People with high math anxiety have a reduced working memory capacity and, because working memory is required by many arithmetic and mathematical tasks, math anxious subjects perform more poorly on these tasks than low anxious subjects. There is conflicting evidence in the literature regarding memory for emotionally arousing stimuli. Many studies have reported that memory is better for either pleasant or unpleasant material than it is for emotionally neutral material. But there is some evidence that traumatic stimuli can inhibit memory for simultaneously presented neutral material.

There is extensive evidence that cortisol level is correlated with memory. But sometimes elevated cortisol levels have been shown to have a positive effect and sometimes a negative effect on memory. One possible explanation is that various researchers induced or measured cortisol levels at different points on the Yerkes-Dodson function. Further complicating the picture is the fact that few stress/memory experiments have taken account of possible state

dependency effects. Thus it is unclear whether the effects of elevated cortisol levels, whether facilitative or adverse, are the same on encoding and retrieval processes in memory.

Not only does stress affect and often limit memory, but also memories of stressful events can provide a basis for intrusive thoughts, resulting in persistent, protracted, lingering, or chronic stress – a kind of vicious circle. To date, no one has reported on the possible detrimental effects of intrusive thoughts on cognitive task performance.

Environmental Conditions that Induce Stress

Time Pressure

One of the most obvious ways to put a performer under stress is to impose time limitations on the task or to give frequent "hurry up signals." Intuitively, most people feel that they do not do their best work under time pressure, although there might be important individual differences in this regard. It is surprising therefore to discover that the literature contains very little evidence on the effects of time pressure on cognitive performance. Moreover, those studies that have been reported find rather obvious and uninteresting results.

The task used by Van Galen and van Huygevoort (2000) required subjects to make cursor movements to targets varying in width and distance. On the basis of the theory of van Ghemmert and Van Galen (1997), which has been described elsewhere, the authors tested the prediction that time pressure and dual task load would influence error rates and movement variability, together resulting in biomechanical adaptations of pressure on the cursor control. The latter is seen as a manifestation of a filtering strategy to cope with increased neuromotor noise levels. The results confirmed that, especially under time pressure, error rates and movement variability were enhanced, while cursor control pressure was higher in both conditions of stress.

Ashcraft (2002) has demonstrated that the performance decrement suffered by math anxious subjects on quantitative problem solving is in part attributable to a

compromised working memory. In an extension of this idea, Kellogg, Hopko, and Ashcraft (1999), following Matthews (1996), tested whether the limitation of working memory observed in anxious subjects might be the result of worry, i.e., that their consciousness is occupied to some extent by concern over the likelihood of poor performance. Time pressure could be a factor contributing to worry and thus to the poorer performance of anxious subjects. These researchers found, however, contrary to the worry hypothesis, that time pressure lowered performance of both anxious and non-anxious subjects equally. Thus the worry resource model was not supported by their data.

When response time deadlines are imposed in quantitative tasks, such as addition or multiplication, performers often adopt a strategy that is different from the one they would use in normal circumstances. Typically, these adopted strategies place less of a demand on working memory. For example, Campbell and Austin (2002) showed that adult subjects shifted from a calculation-based or procedural strategy to a direct memory retrieval strategy to perform mental addition problems when they were put under time pressure. Performance suffered as a consequence of this shift, especially in more difficult problems

Entin and Serfaty (1990) reported an experiment to investigate the effects of time pressure on decision-making. Their paradigm involved a single decision maker whose job was to classify submarine sonar returns as coming from a friendly or enemy boat, on the basis of differences in average pump noise frequency between the two classes. After being given the value of the unknown submarine's measured pump frequency, the subject either classified the submarine as friend or foe or, for a cost, asked for more information. This information was chosen to be either another raw measurement (probe) or the opinion of an automated consultant. Two distinct subject populations were used, civilian (engineering firm employees and college students) and military. For both groups, performance under time pressure was significantly poorer than normal. The effects of time pressure are, then, what one would intuitively expect them to be. The researchers provided no speculation as to the underlying processes that might be

engaged by time pressure and how they operated to affect performance. Furthermore, because only two conditions were used, the experiment yields no evidence on the shape of the function between performance and time pressure.

Two person command and control teams were trained, in an experiment reported by Lehner, Seyed-Solorforough, O'Connor, Sak, and Mullin (1997), to make decisions using a prescribed strategy following a set of simple decision procedures. The authors were interested in the impact of time stress on the decision-making performance of teams. The results supported the conclusion that prescribed decision procedures, which were somewhat counter-intuitive, would be more vulnerable to the effects of time stress than other more familiar and intuitive decision procedures. In addition, the results suggested that the subjects adapted inappropriately to time stress. As time stress increased, they began to use a decision processing strategy that was less effective than the strategy they were trained to use, reverting to procedures that were more familiar to them. While this study focuses on team performance, there is nothing in the data to suggest that same results would not be obtained with individuals working alone.

A study by Ozel (2001) provides greater insight into the effects that time pressure can have on fundamental cognitive processes. Ozel examined the manner in which stress, created by the threat of fire, affects how people process information provided to them about the correct escape route. Ozel reported that modest stress was beneficial to performance, but that extreme time pressure impeded performance by narrowing the range of environmental cues attended to or processed, an outcome predicted by Easterbrook (1959). In addition, the use of negative coping styles increased with time pressure.

Work Load and Overload

It is difficult, for reasons mentioned elsewhere in this review, to create extreme or prolonged conditions of stress in the laboratory. Laboratory studies generally focus on relatively weak acute stress. An example involves adding

workload or secondary task requirements to a primary or focal task. Subjects often find these additions to be stressful at least at the outset and they can adversely affect primary task performance. Given some experience or practice, however, individuals can often find ways to accommodate to the greater demands of doing two things at once.

Consider the work of Matthews, Sparkes, and Bygrave, (1996), who tested the hypothesis that driver stress is associated with performance impairment mainly because stress-prone drivers are vulnerable to overload of attentional resources. In other words, those who are susceptible to the effects of stress suffer from limitations on attentional resources and are more distractible by irrelevant non-driving events. Young subjects performed a simulated drive concurrently with a grammatical reasoning task, presented either visually or auditorily. In this experiment, the patterns of dual-task interference predicted by attentional resource theory were actually not found, although some interference was apparent with the auditory reasoning task. Measures of vulnerability to driver stress and intrusive cognitions were related to impaired lateral control of the vehicle mainly when task demands were relatively low, contrary to the overload hypothesis. These data indicate that performance in this task paradigm is characterized by adaptive mobilization of effort to meet changing task demands. Stressed drivers adapted to high levels of demand fairly efficiently. The levels of stress involved here obviously fall within the range that can be compensated for by strain or mobilization. But, in contrast, Metzger and Parasuraman, (2001) found that, at higher levels of overload, created by a secondary task during driving in high traffic density and assessed by HR and self-report measures, performance does gradually but significantly decline. Parallel results were reported by Zeier (1994) for air traffic controllers.

With practice, people often find ways to incorporate secondary task requirements into the strategy they use to perform the primary task. Healy, Wohldmann, Parker, and Bourne (submitted), for example, recently reported evidence of this phenomenon in a series of experiments on time estimation. Two

groups of subjects were trained on a time estimation task under stress created by various secondary tasks. One secondary task was relatively easy, requiring the repeated articulation of a given letter of the alphabet. The other secondary task was quite difficult, requiring recitation of the alphabet backward by three's starting with a given letter. Performance in these conditions was compared to that of a third, control group, trained without the stress of a secondary task. Training led to improvements in performance in all three conditions but training with the difficult secondary task degraded, or strained, performance considerably relative to the other two conditions. Importantly, removing the secondary tasks after training in a transfer task actually impaired performance for those subjects trained with either secondary task relative to the control. In fact, performance was worse after training for subjects in the difficult secondary task condition than it was at the beginning of training for subjects in the control condition. This is a surprising and unique finding with crucial implications both for training and for understanding workload and stress effects. It is consistent with the procedural reinstatement principle proposed by Healy and Bourne (1995) if it is assumed that the procedures used by subjects to estimate time somehow accommodated the requirements of the specific secondary task. The idea is that when the secondary task is removed in the transfer session, new procedures are required to perform the primary task alone, leading to an initial performance decrement.

The results of this study raise an interesting empirical question about training to contend with stressors. Training may be specific to the particular stressor or stressors that are present during practice. The procedural reinstatement principle implies that training with one stressor will not necessarily generalize to test conditions (i.e., to retention, transfer, or retraining) under other stressors. For example, training under the stress of time pressure to respond may enhance subsequent performance under another type of time pressure, but may not adequately prepare individuals for subsequent performance under conditions of fatigue or work overload. In fact, training under time pressure may put a person at a disadvantage when tested under different adverse conditions. The results of Matthews et al. (1996), who studied driving under various stress conditions are

consistent, although not definitive, with respect to this expectation. Training under two or more adverse conditions may support wider generalization at test even when the adverse conditions at training do not match those at testing, in agreement with a variability of practice hypothesis of Schmidt and Bjork (1992). What actually happens, of course, is an important empirical question that needs to be addressed at some point in this project.

Information overload threatens our limited cognitive capacity and can quickly degrade performance in many daily tasks (for the classic argument, see Miller, 1956). Fitts (1966), for example, demonstrated that an overload condition created by time pressures significantly increased error rates in a complex reaction time task. Under circumstances of high information load, artificial memory aids can be especially beneficial to performance. In most experiments that have examined time pressure, the decline in performance is gradual rather than catastrophic, as would be case if cognition was completely overwhelmed. As an example of how this works, consider a recent series of experiments by Burrows (2002) that examined how workload variables such as amount of information, speed of information presentation, and secondary task requirements, interact to create a condition of overload and how they influence recognition memory.

Burrows (2002) measured the recognition of previously presented words, with the length of the memory list increasing with each presentation. Gradual declines in recognition performance were observed over trials (and with expanding lists). It is important to note that performance degradation was gradual, rather than abrupt. Subjects were able to adjust to conditions of overload by maintaining in memory some significant portion of the materials to be retained. When rate of information presentation was increased, performance was adversely affected, but the slope of degradation function associated with increasing the size of the memory list was not changed. That is, recognition memory decreased gradually as the size of the list increased and as the rate of presentation increased, but these variables did not interact. In one final experiment, Burrows required his subjects to perform a second task simultaneous with recognition memory. Several new items were

added to the memory list on each successive trial, and, in addition, subjects were instructed to forget or eliminate a small subset of earlier items. Thus, each memory trial required not only adding new items but also deleting others and a reorganization of the remaining memory list. The requirement to delete and reorganize in memory degraded overall performance. The effects were entirely attributable to mishandling the deleted items. That is, performance on retained and added items was the same in the standard learning condition. But subjects were completely incapable of retaining the current status of deleted items, sometimes recalling them as part of the list and sometimes not.

Burrows's studies suggest two major conclusions regarding the workload placed on memory. First, expanding the length of a list to be remembered causes a gradual (non-catastrophic) decrease in performance. Second, the requirement to reorganize an expanding list does result in an abrupt decline in performance mainly attributable to a complete forgetting of the status of deleted items. The practical implications of these results are likewise two-fold. First, when new information is periodically introduced into a task, modest memory aids, such as temporary reminders of the new items, will offset the increased memory load. However, when reorganization and up-dating are required, aids that keep track especially of the once-but-no-longer relevant items are especially helpful. Memory up-dating of the current state of a complex systems is uniquely vulnerable to the effects of information load and possible other stressors.

Adding a secondary task to a primary task can create an information overload situation, but information overload can also occur within the context of a single, primary task. Suppose individuals are required to learn rapidly a large quantity of new facts in some specific domain, which is commonly the case with the introduction of new complex systems into the workplace. The effects of this kind of information overload on learning and subsequent performance are not well understood by cognitive psychologists but should generally be detrimental. If the overload is severe, then it will impose a form of cognitive stress (Humara, 2002), and it is important for the operator to develop coping strategies to deal with this

stress. Van Overschelde and Healy (2001) recently reported a series of experiments to investigate how the level of knowledge participants have about a domain affects their ability to cope with a large number of new, non-domain relevant facts about persons within their domain of expertise. To create a situation of information overload, Van Overschelde and Healy required subjects to learn 12 new facts about each of 12 persons (i.e., 144 new facts in total). They found that subjects who had a high degree of knowledge in a particular domain (e.g., about baseball or movies) were better able to learn new facts about famous persons from that domain than to learn new facts about persons from a domain of which they had a low degree of knowledge, even though the facts themselves were not relevant to either domain. In a second experiment, Van Overschelde and Healy created a novel knowledge base, by having subjects learn five facts about each of six previously unknown persons, and one fact about each of six other persons. Two days subsequent to this pre-training experience, participants learned 12 new facts about each of the 12 persons. Participants were significantly better at learning new facts about persons for whom they had learned five facts initially than about persons for whom they had learned only one fact initially.

As noted earlier, these studies suggest that one mechanism for coping with information overload and reducing the stress overload engenders is to provide connections between the new facts to be learned and an existing knowledge base. The general principle is that the acquisition and retention of new, factual information is facilitated whenever that new information can be linked to an existing knowledge base. The mechanism underlying this strategic-use-of-knowledge principle is based on the provision of a retrieval strategy supported by factual information that already exists in long-term memory. Future experiments might profitably focus on the provision of different retrieval strategies to validate their effectiveness and to document which strategies work best.

Fatigue and Sleep Deprivation

Laboratory studies. When a people work at a continuous, demanding task, such as the operation of a complex electronic system, their performance might be affected by at least two opposing processes. First, performance might improve, becoming more accurate and faster as operators master the skills required of the task. Second, performance might deteriorate as individuals suffer the effects of fatigue over long periods of uninterrupted work. The effects of fatigue are likely to be transient, dissipating over periods of rest interpolated between periods of work. The effects of skill acquisition, however, should be relatively permanent, persisting long after fatigue has worn off. Testing this differential effect of prolonged work has yet to be adequately accomplished and is likely to be the focus of future research in the general domain of stress (caused by fatigue) and cognition.

Healy, Bourne, and colleagues (Buck-Gengler & Healy, 2001; see also Fendrich, Gesi, Healy, & Bourne, 1995) have recently reported several experiments addressing certain aspects of fatigue in a repetitive data entry task. In one experiment, there were two sessions separated by a one-week delay. In each session, subjects typed strings of 4-digit numbers viewed as numerals displayed on a screen. A short break halfway through the first (training) session allowed subjects some degree of recovery from fatigue. These researchers found that, during training in the first session, accuracy of performance decreased from the first to the second half of the session and across blocks within each session half. This finding documents the successful induction of fatigue during training. Nevertheless, these researchers also found that, during training, response time decreased from the first to the second half of the session and across blocks within each session half, suggesting that practice and fatigue combined to lead to a speed-accuracy tradeoff.

The observed speed-accuracy trade-off illustrates two important general caveats concerning the effects of stressors, such as fatigue, on performance. The first is that stress effects may be different for different measures or indices of performance (in this case, speed and accuracy). The second is that the effects of stressors may not always be harmful. This latter conclusion, of course, follows

from the Y-D law, which specifies an optimal level of arousal (resulting from stress) for any person and any task. But what is demonstrated in these experiments is slightly different; here one stressor actually facilitates response times and simultaneously inhibits accuracy. The generality of this observation needs to be checked in other tasks and training conditions. For example, in a more cognitively demanding task than data entry, such as mental calculation (e.g., Rickard, Healy, & Bourne, 1994), fatigue effects might be less severe or possibly non-differential on performance measures.

The observation that fatigue or other stressors might not matter or might even have a beneficial effect on some measures of performance seems inconsistent with common sense and is certainly contrary to corporate wisdom. Every manager knows that if you keep people up for 48 hrs, they will not handle the workload as well as they can when they are fresh. To interpret these results accurately, we need to keep in mind that the level of fatigue induced in laboratory studies might simply be too minimal to cause serious performance degradation. It is also important to recognize that most cognitive studies performed in the laboratory have addressed acute fatigue developed over relatively short work periods. Principles uncovered in these conditions are unlikely to apply to more chronic or stronger fatigue states. Therefore, in the future, experimenters should try to find ways to expand their research on fatigue both to more intense and to chronic conditions. This expansion might be accomplished, for example, by the use of sleep deprivation or imposed deviations from normal circadian rhythms.

The results of Soetens, Hueting, and Wauters (1992) show that the effects of fatigue might vary with task difficulty. Using a numerosity judgement task, these researchers found that, under fatigue, errors were greater for larger displays (7+ dots in the visual field to be judged). No difference between fatigued and nonfatigued subjects were observed at smaller displays. Small numbers can be estimated accurately by an automatic process known as subitizing. Larger numbers require attention and mental work, including counting. Fatigue reduces or eliminates controlled processing required by larger numbers, leading to more

errors. Their conclusion was that fatigued subjects tend to avoid or fail at complex decisions.

Steyvers and Gaillard (1993) examined the possibility that knowledge of results (KR) and reward might compensate for the negative effects of sleep deprivation in a choice-reaction task. They found that the effect of signal degradation on performance was aggravated by sleep loss and time-on-task, confirming the observation of Soetens, et al. (1992). They also reported that KR improved performance, especially when signals were degraded. Reward counteracted to some extent the effects of time-on-task owing to lack of sleep. Consistent with the finding of Buck-Gengler and Healy (2001), performance also improved as the result of a brief task interruption after 30 min. of work.

EEG measures are sensitive to abnormal conditions such as fatigue and sleep deprivation. This fact suggests the possibility that neuro-physiological measures, such as the EEG, might be used to differentiate stress states of the organism from normal or other abnormal states. Gevins and Smith (1999) reported that both alcohol intoxication and fatigue reduced the accuracy of performance in a working memory task and that these effects were associated with changes in spectral characteristics of the EEG. Human observers and digital networks trained on human data could discriminate fatigue and alcohol states in the EEG from normal alert states with accuracy well over 90%.

Natural tasks. There has been a fair amount of research on fatigue in more natural situations. For example, Matthews and Desmond (2002) induced fatigue in a simulated driving task by requiring subjects to perform a demanding secondary task while driving. Their induction procedure produced subjective feelings of fatigue and stress and of heightened workload. With respect to driving performance, fatigue induction increased errors of heading, steering, and reduced perceptual sensitivity in the secondary task. These researchers also report, however that added motivation partially overcame these adverse effects of stress. They attributed the primary effect of a secondary task (1) to the division of

attentional resources in the dual task case and (2) to a failure to adjust effort to level of task demands.

Schellekens, Sijtsma, Vegter, and Meijman (2000) demonstrated some persistent effects of demanding day-long office work on cognition. These researchers administered a memory search task before, during, immediately after, and 2 hrs. after either an easy day of work or a demanding day of work. Performance measures on the search task were RT and accuracy. Effort on task was measured physiologically by HR. Accuracy decreased slightly on the immediate test after a difficult day, relative to tests administered before and during the work-day. Also, subjects invested significantly less effort in the memory task after a difficult day relative to an easy day. In a delayed test, a speed/accuracy trade off was observed. After a demanding day, RTs increased and accuracy decreased in the delayed measure, results similar to those reported by Buck-Gengler and Healy (2001) obtained in a laboratory setting. Apparently, under some circumstances, fatigue has latent effects that only show up after sufficient passage of time. Further, recovery from fatigue requires rest and time away from task.

Many occupations require not only extended work periods, exceeding the normal 8 hrs, but also are physically demanding and provide few if any breaks. Operators of public transportation equipment are a good example of this kind of work environment. Raggatt and Morrissey (1997) measured stress and arousal in 10 long-distance bus drivers during 12-hr driving shifts and at matched times on non-driving rest days. The objectives of the study were (1) to compare the stress measures collected on the road, which included HR, BP, catecholamines, cortisol, state anxiety, and self-ratings of stress and arousal, with matched rest-day baseline measures, and (2) to investigate the pattern of arousal over the course of shifts. It was expected that certain psycho-physiological changes would take place during long-distance driving and these changes would be associated with driving fatigue. Cardiovascular and catecholamine data were elevated across the entire work-day, compared with rest days. Self-reported stress and state anxiety were elevated only at the pre-shift measure, and these elevations were interpreted to be the result of

anticipatory anxiety and additional work demands at the beginning of the shift. Decelerating activation from the 9th-12th hrs of driving were reflected in slower HR and lower subjective arousal ratings. Apparently drivers experience a release of tension when they anticipate the end of the shift and therefore deactivation is a signal or precursor to the onset of fatigue. Measures of driving performance remained relatively stable over a 12 hr shift. Experienced drivers seem to have acquired coping strategies that allow them to maintain stable performance levels when work sessions are of known duration and do not exceed 12 hrs. As in the case of long-term isolation, cognitive effects of stress appear to be ameliorated by knowledge that the stressful situation, although long, is time limited

But Raggatt amd Morrissey (1997) also found that performance falls when shift length is uncertain or exceeds the normal 12 hr limit. Performance degrades before changes are evident in physiological measures. This result is consistent with the conclusion of Hancock and Vasmatzidis (1998) that continued work requirements after performance efficiency begins to fail, but before current physiological limits are reached, is inappropriate for both the safety and the productivity of the individual worker, their colleagues, and the systems within which they operate. Behavioral performance assessment should therefore supercede physiological assessment as the primary exposure criterion, although physiological measures still provide important supplementary information.

Even without a work requirement, long periods of sleep deprivation can have serious cognitive consequences. Baranski, Gil, McLellan, Moroz, Buguet, and Radomski (2002), for example, showed that 40 hrs of sleep deprivation severely affected cognitive performance on seven cognitive tasks -- serial reaction time, logical reasoning, visual comparison, mental addition, vigilance, and multitasking -- to essentially the same degree on all tasks.

Samel, Wegmann, Vejvoda, Drescher, Gundel, Manzey, and Wensel (1997) investigated two-person crew extended range operations over 2 consecutive night flights with a short layover. Pre-, in-, and post-flight measurements of sleep, task

load, fatigue, and stress using EEG, ECG, motor activity and subjective ratings were collected for 11 rotations (22 flights) from 22 male pilots. Average flight times were 9 hrs with an average daytime layover of 13 hrs 30 mins. Results showed that sleep during layover was shortened by an average of 2 hrs relative to normal. Fatigue was more pronounced during the return flight and several pilots scored their fatigue at a critical level. Motor activity, brain wave activity, and HR indicated drowsiness and a low state of vigilance and alertness during both night flights, but these effects were more pronounced during the return flight. A survey of military pilots reveals that they suffer chronically from sleep deprivation (Caldwell & Gilreath, 2002). Insufficient sleep, combined with rotating schedules and other work demands, no doubt contributes to the perception that fatigue is a widespread problem in the aviation community. These results indicate the importance of continuing to employ fatigue-reduction strategies in training and operational environments.

To what degree can fatigue effects be offset by periods of rest? Neri, Oyung, Colletti, Mallis, Tam, and Dinges (2002) arranged for 14 2-man crews to participate in a 6 hr, uneventful, nighttime flight in a Boeing 747-400 flight simulator. Crew members in the treatment group received 5 short breaks spaced hourly during cruise; the 14 crew members in the control group received 1 longer break in the middle of cruise. The treatment group reported significantly greater subjective alertness for up to 25 min. post-break, with strongest effects near the time of the circadian trough. There was no evidence of objective vigilance performance improvement at 15-25 min. post-break, with expected performance deterioration occurring due to elevated sleep drive and circadian time. In situations that require sustained attention over a prolonged period of time, e.g., during a long overnight flight, brief and regularly spaced breaks improve alertness and performance.

What about stimulating drugs? Can they offset the effects of fatigue, without causing adverse consequences of their own? Caldwell (2001; see also Caldwell & Gilreath, 2002) reported a quasi-experimental comparison of modafinil

(Provigil (R)) and dextroamphetamine (Dexedrine (R)) on the performance of sleep deprived pilots. Subjects were given either dextroamphetamine or modafinil and then undertook a flight simulation. Results indicate that there were no differences between the 2 stimulants. However, in the majority of cases, it was clear that performance, subjective mood ratings, and physiological indices of alertness were substantially better under both drugs than under placebo. Thus, with the exception that modafinil produced more spontaneous reports of side effects than dextroamphetamine, the overall results indicated equivalent efficacy with the 2 compounds.

There are at least two studies which have examined the interaction of sleep deprivation with other stressor variables. von Restorff, Kleinhanss, Schaad, and Gorges (1989) investigated human tolerance limits for sustained performance on several simple psychological tests. Subjects performed continuously for 72 hr, with only 1 hr of sleep permitted after 32, 48 and 60 hr. The present experiment examined whether such sustained performance might be additionally influenced by mild hypoxia together with correspondingly increased carbon dioxide levels (stale air). Performance showed the expected decrease with increasing duration of sleep loss. However, findings show no clear differences in performance between the control and the hypoxia groups. There were, however, more pronounced decreases over time in both group in the more complex memory tasks as compared to simple reaction time and vigilance tasks.

Larsson (1989) looked at the interaction of sleep deprivation and the stress created by a noisy work environment. He measured the performance of Swedish military personnel on an artillery simulator under calm conditions, noisy conditions, and noisy conditions with 27 hrs sleep deprivation. Under all conditions, subjects who appraised the task as a challenge demonstrated positive coping and better performance, relative to those who appraised the situation as a threat. Performance degraded and negative coping increased with increasing sleep deprivation.

Noise

Noise or atonal sound is everywhere in the modern world. People normally do well in adapting to these ambient and sometimes disagreeable sounds. But there are circumstances in which noise can be stressful enough to produce some adverse changes in human behavior. Early on, Hockey (1979) reviewed the psychological literature on noise-induced stress, concluding that there were five primary effects. First, stressful noise activates the performer often to a level that exceeds optimal for the task at hand, resulting in an increase in the rate of work but also an increase in errors. Second, stressful noise changes the performer's policy for allocating attentional capacity, resulting in an apparent reduction in short-term or working memory. Third, attentional selectivity -- that is, limiting the attentional field, bringing relevant stimuli into sharper focus, focusing on the here and now, reducing memory search, relying on automatic as opposed to deliberate functions -- is increased. Fourth, there is an increase in response selectivity. Finally, stressful noise reduces the performers confidence in his/her ability to do the task at hand. These effects were observed primarily in studies using laboratory induced stress and laboratory tasks.

Later, Kjellberg (1990) reviewed the psychological literature on the effects of noise in the work environment, emphasizing moderate-intensity noise (e.g., computers, printers, and ventilation systems). He found reports of significant distraction, and sleep disturbance in individuals who worked under constant noise conditions. He also found evidence of noise effects on reaction time (RT), vigilance, and verbal comprehension tasks. But, in many respects, the existing research presented a rather inconsistent picture of noise effects in natural work environments. Kjellberg (1990) recommended that, because of the potential seriousness of the nonauditory, cognitive effects of noise, more attention needs to be given to these effects in the occupational setting and in the research laboratory. Little has changed in the last 10 years to modify that recommendation.

Larsson (1989) reported that performance by Swedish military personnel on an artillery simulator, a task requiring target identification, target tracking, decision making, and perceptual-motor co-ordination, degraded significantly in noisy conditions relative to calm and quiet conditions.

Kjellberg, Landstroem, Tesarz, et al. (1996) followed up a review of the noise literature (Kjellberg, 1990) with an examination of some of the factors that influence subjective responses to noise in 439 persons working in offices, laboratories, or industrial settings. Information about the workers' subjective assessment of their working environment was collected by questionnaires. An annoyance index and a distraction index were formed on the basis of a factor analysis of questionnaire data. Annoyance was found mainly to be related to sound level, self-rated "necessity" of the noise, hearing status, and gender. Distraction was most strongly related to degree of self-control of the noise and noise predictability. The most critical noise sources for the annoyance response were other machines than those used by oneself, whereas telephone signals and conversations had the largest effect on distraction. Despite the annoyance and distraction effects of workplace noise, no significant influence on quality or quantity of work performance was detected. A moderate level of workplace noise might be stressful, but its potentially degrading effect on performance appears to be counteracted by extra effort in most circumstances.

In a related study, Gomes, Martinho Pimenta, and Castelo Branco (1999) investigated the effects of prolonged workplace exposure to large pressure amplitude (-90 dB SPL) and low frequency (<=5500 Hz) noise, a more serious level of noise pollution than examined by Kjellberg et al. (1996), on attention and memory. Their subjects were 40 male workers employed as aircraft technicians, occupationally exposed to noise for a long period of time (range 13-30 yrs), and 30 educationally and age-matched male controls. Subjects performed an auditory discrimination task during which event related cortical potentials (ERPs) were recorded. In addition, the Wechsler Memory Scale [WMS] was administered to all subjects. The P300 latency in the ERPs was significantly longer, and the amplitude

significantly smaller in the group exposed to noise. The WMS memory quotient indicated a significant difference between groups, with exposed subjects showing poorer results. This difference was especially marked on the immediate verbal memory sub-scale. The suggestion is that the more intense and prolonged the noise that occurs in one's work environment, the more stressful those circumstances are and the more serious the implication for degraded performance.

Using a different approach, Evans, Hygge, and Bullinger (1995; see also Hygge, Evans, & Bullinger, 2002) were able to demonstrate significant cognitive losses attributable to intense noise, that are ameliorated by time out of the noisy environment. Hygge, et al. conducted a naturalistic experiment that involved children (average age = 10 yrs.) living near to the old and the new Munich International Airports. By taking behavioral measures at different points in time, these researchers created two groups of subjects at each site: those subjects who were currently exposed to aircraft noise and those not so exposed, the groups being matched for socioeconomic status. Self-reported stress levels were higher in groups exposed to aircraft noise. Long term memory, short term memory, and reading measures were impaired in the noise groups, but both improved after noise was eliminated by the airport switch. Some speech impairment was noted in children exposed to noise near the new airport. Apparently, the degrading effects of noise on cognition, although severe, are mostly transient, at least in young children, and recovery follows the removal of the noise stressor.

Results attributable to noise are complex and not presently well-understood. An example of the complexity of these effects is found in a study reported by Hygge and Knez (2001). In a measure of attention, ventilation noise produced a speed/accuracy trade-off, with subjects performing faster but less accurately in noisy conditions. In addition, noise reduced recall of emotionally-toned but not neutral words. There were some non-additive interactions with other stressors that further confounded the outcome. What is needed to resolve the differences observed in these studies and to clarify the effects of noise pollution on

performance is a single coherent experiment in which noise intensity and duration are systematically varied as subjects perform a range of cognitive tasks.

Finally, using a vastly different approach than most other studies of noise, Schmidgall (2001) examined the initiation and execution of speeded responses on a clock face display. Subjects were presented with a clock face, which consisted of a fixation point (labeled with the letter "X") surrounded by a circle of digits, 1-8. Subjects were instructed to move a cursor using a mouse onto the "X" in the center of the clock face to begin each trial. A digit then appeared above the "X," and subjects were instructed to find this digit on the clock face and move the cursor on a direct path from the "X" to the target digit represented in the circle (see, Healy, Buck-Gengler, Barshi et al (2002) for details). Subjects were trained to respond to the stimulus (i.e., the target digit) across a fixed number of training trials. On all trials, the stimulus was shown until the response was made and the digits occurred around the clock face in a standard clockwise arrangement. At the time of testing, along with trials equivalent to those shown during training, the subjects were introduced to two environmental or situational stressors, which occurred during a limited number of testing trials. On these critical trials either the target digit was presented for only a very short duration and/or the digits on the clock face were randomly arranged. In addition to these two types of environmental stressors, some subjects were exposed to a loud, continuous irritating (according to subjective reports) beeping sound throughout the testing period. Thus, the effects on performance of the first two types of stressors were examined with and without the third type of stressor. Schmidgall found that subjects responded more quickly to the sequential clock face arrangement than to the random arrangement. There were no overall effects of noise or of the abbreviated stimulus duration, although of these variables exacerbated the adverse effects of random clock faces. Consistent with the Y-D function, stress has a degrading effect primarily when the task is difficult.

Ambient Temperature

Human beings sometimes need to adapt to extreme, unknown, or isolated environments. This adaptation requires changes in the normal regulation of psycho-physiological homeostasis (Farrace, Cenni, Tuozzi, et al.1999; Hammond, 2000). Experimental evidence indicates that even relatively mild thermal stress may affect human performance (Enander, 1989). Tasks requiring manual dexterity and muscular strength are clearly impaired by cold exposure, while decrements in vigilance performance and endurance are well-documented effects of heat stress. The considerable variation in results regarding the effects of thermal stress may, to some extent, be attributable to complex interactions between exposure conditions, task characteristics, and individual factors.

Heat. Hot and humid environmental conditions are known in the folklore to have debilitating effects on human performance, with the consequence that the effectiveness and efficiency of individual and team operations are severely compromised. While the adverse effects of thermal stress on operators' physiological capability are well established, there is less scientific evidence available about cognitive performance. Hocking, Silberstein, Lau, Stough, and Roberts (2001) administered a number of psychometric tests to investigate the impact of thermal stress on cognitive performance. These tasks measure a range of cognitive processes including attention, memory, verbal learning, information processing, and concentration. In addition, the electrical activity of subjects' brains was measured while they undertook these cognitive tasks. Functional brain imaging provided topographical information on changes in electrical activity in response to thermal stress during cognitive performance. Results indicated that subjects experienced increasing cardiovascular strain through thermally neutral to thermally extreme conditions. There were, in addition, marked differences in the electrical responses of the brain when subjects were thermally strained, suggesting an increase in the utilization of neural resources or effort by subjects to maintain the same level of performance as under thermally neutral conditions. The

psychometric test battery showed some deficits in working memory, in information retention, and in information processing under thermal stress.

Vasmatzidis, Schlegel, and Hancock (2002) reported a study of the effects of heat stress on time-sharing performance. Participants performed 3 dual-task scenarios and a multiple-task scenario for 2 hrs in each of 6 climates. The dual tasks were (1) display monitoring with mathematical processing, (2) memory search with mathematical processing, and (3) unstable tracking with memory search. The multiple task scenario included visual monitoring and auditory discrimination tasks. Results indicated significant heat stress effects resulting in inferior performance on display monitoring, tracking, and auditory discrimination. These effects were cumulative over time under stress.

As noted by Hocking et al. (2001) and others, performers can often mobilize additional effort to offset the debilitating effects of stress (supra-optimal arousal) on performance.   A study by Razmjou and Kjellberg (1992) confirmed this result. Stress effects created by ambient heat (40 decrees Celsius) on a simple and a complex serial four-choice reaction time task were examined. Core temperature, HR variability, and subjective reports of stress level and of effort allocation were monitored over an 80 min. work period. Performance in both RT tasks deteriorated over time in heat but could be offset somewhat by the allocation of additional effort to the task, as determined by subjective reports.

Cold. There are few studies that examine directly the effects of hypothermia on cognitive performance. One that did, using cold water immersion to induce hypothermia, was reported by Giesbrecht et al. (1993). These authors found that tests placing relatively minimal cognitive demands on individuals, such as auditory attention, the Benton visual recognition test and forward digit span, were unaffected by either initial cold water immersion or by eventual central cooling. On the other hand, tests requiring relatively greater mental manipulation and short term memory (i.e., backward digit span) or processing and analysis (i.e., Stroop test) showed a slight improvement upon cold water immersion (perhaps related to

increased arousal and/or learning) but a significant decrement following later more serious central cooling of 2-4 degrees C. Thus, relatively simple tasks were unaffected by central cooling, whereas more complex tasks were adversely affected. Central nervous system cooling probably interferes with mental processing although discomfort and/or the physiological and physical effects of cold on the neuromuscular aspects of speech, required for responses to some of the tasks, may also affect performance.

In a somewhat more naturalistic situation, Slaven and Windle (1999) undertook a psychological assessment of submariners undergoing a survival trial simulating conditions in a disabled submarine. The aim was to determine whether the environmental conditions in a submarine escape compartment had any effects on cognitive performance. The study was conducted in an environmental chamber in which the temperature fell from 22 deg. C to 4.4 deg. C over 2 days and then remained at 4.4 deg. C for 5 days. Male volunteer subjects were tested periodically on choice reaction time [RT] and short term memory and showed no significant performance decrements. However, anecdotal evidence from observations and subjects' self-reports suggest that sustained performance was impaired gradually as ambient temperature decreased. Results suggest that motivation can make up for adverse, stressful conditions if the tasks are not high-level or continuous.

Intense environmental heat or cold in natural or in laboratory circumstances can have an adverse effect both on behavior and on correlated brain processes. Some performance effects can be offset by extra effort, but if abnormal conditions persist, performance eventually suffers. The best recommendation one can make on the basis of the available data is to try to keep ambient temperature optimal for the given task and individual.

Miscellaneous Stress Variables: Extreme Environments

A variety of other imposed or natural environmental conditions are associated with stress in human beings. Some of these variables have been given

cursory examination by cognitive psychologists. The results are interesting, but unsystematic. Here we will review the effects of two of these variables, isolation and hypoxia, which are sometimes associated with extreme environments.

Isolation. Social isolation, usually involving confinement, is perhaps the most important of these miscellaneous other stress conditions because it is a common consequence of space flight. Isolation creates long term or chronic, in contrast to acute stress. Many researchers have referred to Antarctic expeditions, and other similar protracted exposures to abnormal or extreme circumstances as models of the isolation and confinement that occurs in Space. Sauer, Hockey, and collaborators have investigated health and performance changes in this form of isolation. For example, Sauer, Juergen, Hockey, and Wastell (1999) reported a study of three Russian cosmonauts, tested on a PC-based simulation of a MIR space flight, which included isolation and confinement over time. They found some temporary performance degradations as time passed although for the most part, without the occurrence of emergencies, job performance was acceptably high throughout. The same researchers also reported on the effects of wintering-over by a group of French Antarctic expeditionaries. Again, only minor decrements in performance on cognitive tasks were observed.

Sandal, Vaernes, Bergan, Warncke, and Ursin, (1996) assessed psychological reactions among 67 adults from 17 countries, who were isolated either in hyperbaric chambers or on polar expeditions, environments considered analogs of space flight. The Personality Characteristic Inventory was administered before isolation, and adaptation to the respective environments was assessed weekly by questionnaire. Crews in hyperbaric chambers indicated a steady increase in coping skills over the isolation period. A personality characterized by strong expressiveness and instrumentality predicted superior adaptation in hyperbaric chambers. Members of polar expeditions reported high aggressiveness and anxiety in the first quarter and an increase in homesickness over time. These changes in mood and emotion were not paralleled by changes in performance on a variety of

tasks, however. Results indicate that isolation in hyperbaric chambers and on polar expeditions are reasonable models for different aspects of the Space environment.

Later, Palinkas, Gunderson, Johnson, and Holland (2000) reported an analysis of two data sets collected in Antarctica purportedly to identify features of behavior and performance likely to occur during long-duration missions in Space. In one set, the influence of mission duration and station latitude on a self-report questionnaire regarding mood states was examined in 450 Americans who wintered-over in Antarctica from 1991-1998. In the second set, the influence of crewmember social characteristics, personality traits, interpersonal needs, and station environments on measures of behavior and performance at the end of the austral winter was examined in 657 American men who wintered-over from 1963-1974. Both data sets were used to determine the influence of crew social structure on the behavior of individuals. Seasonal variations in mood were associated with the altered diurnal cycle and psychological segmentation of the mission. Concurrent measures of personality, interpersonal needs, and coping styles were better predictors of mood, particularly depression, and peer-supervisor performance evaluations than baseline measures. Members of crews with a clique structure reported more depression, anxiety, anger, fatigue, and confusion than members of crews without a clique structure. Depressed mood was inversely associated with severity of station physical environment. But again cognitive performance suffered no serious degradation as a result of isolation.

Zulley (2000) compared the results of social isolation experiments performed in a wide variety of environments with studies in Space, focusing on the circadian course of variables such as body core temperature, sleep-wake patterns, mood, and performance. Results show that subjects in isolation can experience disturbances of sleep, mood, and vigilance if their biological rhythms run "out of phase" with clock time. He concluded that, if at all possible, a strict 24-hr time schedule should be kept with regard to environmental, as well as behavioral influences to insure adequate and restful sleep and optimal levels of waking

performance and psychological well-being. No serious degradation in performance tasks attributable to isolation was observed.

Le Scanff, Larue, and Rosnet (1997) assessed cognitive and sensory impairment and associated adaptation problems for 10 scientists and 6 technicians, all clinically normal, who wintered-over for 12 months in the Antarctic. A battery of Standardized Tests for Research with Environmental Stressors (SB) was completed 8 times by all participants during the isolation period, and an adaptability questionnaire (AQ) was completed 2 times for each subject by the expedition doctor and by the subjects themselves. Significant group by session differences were found, with technicians significantly more variable between sessions than scientists. SB showed a sensitive period of adaptation at mid-winter and at the end of the isolation, but performance in the different cognitive tasks did not deteriorate at the same time. No systematic relationship between AQ and SB and job performance was observed.

The purpose of a study reported by Le Scanff, Bachelard, Cazes, Rosnet, and Rivolier (1997) was to investigate group dynamics in a 60-day space-flight simulation. Specifically the goals were to study individual and group responses to the stress factors in this situation. Subjects were 4 scientists placed in isolation chambers for 3 mo. Testing was completed during periods of pre-isolation, isolation, and post-isolation. Direct methods (questionnaires, tests) and indirect methods (observation) were used in an individual and whole group assessment. The group did not show important stress manifestations during the isolation period. It maintained its cohesion, sometimes by opposing external authority. Qualitative and indirect methods revealed much more information than quantitative or direct methods, according to the authors. Performance was maintained at a high level throughout the 60-day period.

The message from all of these isolation and confinement studies seems to be that if participants are well prepared for the required tasks and understand that their confinement and isolation, while protracted, is time-limited, performance holds up

well, although mood can swing quite widely. What unique effects emergencies along the way might have on performance are not clear from any of these studies.

Hypoxia. Isolation and confinement is a type of extreme environment. Intuitively, extreme, that is, non-normal environments should be stressful. With respect to mood and emotional feelings, they probably are stressful. But, they seem to have relatively little impact on the level at which people perform, given the wherewithal and the motivation to perform.

Another form of extreme and potentially stressful environment is created by hypoxia or oxygen definciency. Mackintosh, Thomas, Olive, et al (1988) assessed psychomotor performance in 20 adults on each of 2 mountaineering expeditions. During the first, which reached 5,008 m, simple reaction time (RT) and alertness were measured. During the second, which reached 4,790 m, performance on a 3-choice RT test was measured. In both studies, mean RTs increased significantly at altitude, but only in subjects with marked symptoms of acute mountain sickness. The alertness tests showed no effects in any subjects, although adverse conditions increased the number of errors.

Bonnon, Noel-Jorand, and Therme (2000) examined attentional changes during adaptation to 2 different types of stay at high altitude on 2 different expeditions. The first involved a 16-day trip between 2,000 m and 5,600 m, followed by a 2-day ascent to 6,440 m and back again. The second was a 21-day stay at 6,542 m. The hypothesis tested was that, at high altitudes with attendant hypoxia, decrements in attention would occur as the duration of the stay at altitude increased. Attention was evaluated for 2 experimental groups under normoxia before the climb, under acute and chronic hypoxia during the climb, and under normoxia after the climb. Two control groups were tested only under normoxia. The altitude stay was found to have an adverse effect on the 6,542 m group when compared with the controls. Group performance differed at 2 days and 21 days after their arrival at 6,542 m and after their return to normoxia. When all the test administrations were pooled together the authors noted an interaction between the

level of difficulty of the attentional task and the experimental and control groups; namely, that the difference between the groups was greater for the difficult task than it was for the easy task.

So, prolonged hypoxia degrades some aspects of cognitive functioning. Interestingly, Leifflen, Poquin, Savourey, Barraud, Raphel, and Bittel (1997) demonstrated that a short acclimation protocol based on intermittent exposure to simulated high altitudes produces adaptive processes without major impairment in a choice reaction time task during the acute stages of severe hypoxia. Fowler, Prlic, and Brabant (1994) extended this work in an investigation of the effects of hypoxia on memory storage capacity (using a dichotic listening task) and speed of retrieval from short-term memory. Hypoxia degraded the accuracy of retrieval from memory, but there was no evidence that memory storage capacity was impaired. In a second experiment, using a memory scanning task, some evidence of a slowing of retrieval speed was found. A comparison of task requirements in this and other experiments suggests that slowing of the central executive of working memory may account for the cognitive deficits observed by others under hypoxia.

Conclusions

Despite the common opinion that time pressure is a major contributor to stress, very little research has been reported in recent years that is relevant to this hypothesis. In addition, studies that have been reported are quite limited in scope. They support the conclusion that time pressure increases errors and response variability in some tasks, that a reduction in working memory is probable under time constraints (though this reduction is not traceable to worry about performance levels), that a reduction in cue utilization occurs under time pressure, and that the adverse effects of time pressure are strongest on responses that are unfamiliar and/or non-intuitive. Clearly, the evidence is sketchy. Systematic manipulation of time pressure is needed in future research efforts.

Workload does relate to performance in a variety of tasks and can get so high that task performance suffers. The adverse effects of overload are related in part to the division of attentional resources among the various components of the task to be performed. Especially difficult in these overload conditions is the need to delete previously relevant task material that

for some reason is no longer relevant and reorganize the task as a consequence. Probably the most interesting outcome of recent research on workload and overload relates to the manner in which performers handle or adapt to these conditions. Participants can adjust to minor conditions of overload by increased effort or more effective mobilization and deployment of resources. Two strategies of resource deployment have been identified. In some cases, the performer can incorporate the response requirements of a secondary task into those of the primary task, in effect creating one super-task that subsumes both the primary and the secondary. Another strategy is to try to discover ways to relate the stimulus material that one must deal with to already existing knowledge that might not seem in the surface to be relevant.

Fatigue from prolonged work or sleep deprivation causes feelings of stress and, in some cases, degrades performance. A sometimes-observed speed-accuracy trade-off in fatigue states illustrates two important general caveats concerning the effects of stressors on performance. First, stress effects may be different for different measures of performance. Second, the effects of stressors may not always be harmful. One stressor might actually facilitate one measure of performance and simultaneously inhibit another. Under some circumstances, fatigue has latent effects that only show up after sufficient passage of time. Further, recovery from fatigue requires rest and time away from task. The effects of fatigue might be attributable in part to reduced controlled processing. Incentives have been successfully used to increase controlled processing, effectively counteracting the effects of fatigue.

Well-trained performers seem to acquire coping strategies that allow them to maintain stable performance levels when work sessions are of known duration and do not exceed 12 hrs. As in the case of long-term isolation, cognitive effects of stress appear to be ameliorated by knowledge that the stressful situation, although long, is time limited. Insufficient sleep, combined with rotating schedules and other work demands, no doubt contributes to the perception that fatigue is a widespread problem in the aviation community. Fatigue-reduction strategies should be an important component of training for these tasks. For example, in situations that require sustained attention over a prolonged period of time, e.g., during a long overnight flight, brief, regular breaks improve alertness and performance. Sometimes stimulating drugs can be effective in improving performance, subjective mood ratings, and physiological indices of alertness.

Isolation and confinement are stressful but have little adverse effect of performance in a variety of tasks. If participants are well prepared and understand that their confinement and isolation are time-limited, performance holds up well, although mood can swing quite widely. Prolonged hypoxia, in contrast, degrades some aspects of cognitive functioning, especially those

that emphasize speed of response. An acclimation protocol based on intermittent exposure to simulated high altitudes can be used to offset these effects.

<div align="center">Individual Differences Variables</div>

<u>Trait Anxiety and Stress</u>

Both general arousal level and felt anxiety increase in response to stressful stimulation. Probably the most detailed analysis of anxiety, in response to stress, has been provided by Spielberger (1966; 1972), who emphasized the need to distinguish sharply between state and trait anxiety. Trait anxiety is a relatively enduring personality characteristic which, according to Spielberger, has a strong somatic, non-deliberate, automatic component. State anxiety is a more transitory reaction to context and environmental stimulation, having a major cognitive appraisal component. Speilberger developed reliable paper and pencil measures of these two components of human anxiety. But, most of the subsequent empirical work using Spielberger's analysis relates to trait rather than state anxiety. Researchers have found it difficult, if not impossible, to separate state anxiety from other transitory consequences of a stressful event.

Low trait anxious individuals, as measured by the Speilberger tests, are less prone to the influence of momentary stressful stimuli than are high stress prone individuals. Similarly, the performance of low stress prone individuals on a variety of cognitive tasks is less affected by stress manipulations than is the performance of more stress prone individuals. Further, high trait anxious people show an exaggerated correlation between felt negative affect or anxiety and somatic and psychological stress (see Wofford, 2001; Wofford & Goodwin, 2002; Wofford, Goodwin, & Daly, 1999).

Endler, Speer, Johnson, and Flett (2001) used independent paper and pencil measures of self-efficacy and perceived control of situations to determine which is the better predictor of state anxiety and of performance in cognitive tasks under conditions of stress in both high and low actual control conditions. They found

that self-efficacy was the better predictor of anxiety across all experimental conditions. But neither self-efficacy nor control predicted cognitive performance. So, self-efficacious subjects are better able to handle stress in so far as felt anxiety is concerned, but, in present circumstances, this does not relate to how well they do cognitive tasks.

Ashcraft (2002; see also Ashcraft & Kirk, 2001) have traced the influence of anxiety to working memory, at least in the context of quantitative problem solving. Ashcraft has repeatedly observed an inverse relationship between (math) anxiety and working memory capacity. Ashcraft argues that high anxious subjects have a compromised working memory capacity, relative to low anxious subjects. The same effect is seen when working memory is stretched by the mental arithmetic task itself. That is, when working memory capacity is reduced by requiring subjects to perform a concurrent memory load task, reaction times and errors on mental addition problems are increased. Thus, high stress levels might exert a deleterious effect of performance in quantitative cognitive tasks through the reduction of available working memory resources. Dutke and Stroebber (2001) have demonstrated, however, that these adverse effects of high stress and anxiety can be compensated for, to some degree, both by enhanced motivation of performance and by external processing aids.

Ashcraft's working memory restriction theory of anxiety predicts that high anxious subjects will also have greater difficulty making quantitative analogies based on relations as compared to common concrete stimulus attributes. Abstract rules create more working memory difficulties than do perceptual attributes in general, and anxiety exacerbates the problem. Tohill and Holyoak (2000) induced anxiety in college students by requiring them to perform a difficult speeded arithmetic pre-task. Then, in a follow-on analogies task, anxious subjects produced more attribute than relational responses relative to non-anxious subjects. Consistent with Ashcraft's theory, Tohill and Holyoak conclude that anxiety reduces the scope of working memory, which is more extensively required by abstract relative to concrete analogies.

It is surprising that other forms of memory, e.g., retrospective or prospective memory, have not been examined in the context of individual differences in anxiety or anxiety producing manipulations. It is not clear at the present time whether the effects of anxiety are limited to working memory, as Ashcraft implies, or are more broadly consistent with a general memory constriction hypothesis. It might be, for example, that, as anxiety or stress in general increases, the time line for memory shrinks, resulting in the loss of prospective and retrospective memories even before limitations on working memory are observed. This possibility remains to be explored in future research.

In a variety of cognitive tasks, including decision making and similarity ratings, Pury and Mineka (2001) found that high trait anxious subjects (relative to low trait anxious subjects) are biased to encode (are more sensitive to) affect-relevant information (in words, events, photographs with varying emotional content) than non-affect-relevant information. This effect occurs even if the affect-relevant information is weak or non-salient. Thus, trait anxiety not only narrows the perceptual (or aperceptive) field, as shown by Easterbrook (1959), but also specifically tunes attention to stimuli with emotional relevance, according to Prury and Mineka. Similar and confirmatory findings were reported by Russo, Fox, Bellinger, et al. (2001), who showed that anxious subjects are more likely to free recall mood-congruent stimuli than are low anxious subjects and by Calvo and Castillo (2001) who found that inferences are more often mood-based in anxious as opposed to non-anxious subjects.

High anxiety individuals are also more sensitive to a possible threat in an ambiguous situation than are low anxiety individuals. However, when the threat becomes stronger, more predictable, or higher in probability, high and low anxious subjects respond alike. Apparently, the difference between high and low anxious individuals resides in part in a threshold for perceived threat. High anxious individuals are more circumspect regarding possible threatening events than are low anxious individuals (Calvo & Castillo, 2001). Similarly, Russo, et al. (2001)

demonstrated that, after incidental lexical processing of a list of words, high anxious subjects have better recall of threat-related words than low anxious. But the different disappeared if the pre-processing is semantic rather than lexical. These results suggest that anxiety acts primarily upon implicit as opposed to explicit learning/memory processes.

Other Personality Variables

Other than trait anxiety, few human personality characteristics appear to have been examined for their relationship to stress. Moreover, the studies that have been reported yield a mixed picture. The few studies that are available tend to focus on whether an individual's personality influences in any way how he or she deals with acute stress. Sandal, Gronningsaeter, Erikson, Gravraakmo, Birkeland, and Ursin, (1998) found that Norwegian Army and U. S. Air Force cadets, characterized by strong instrumental and expressive personality traits as measured by the Personality Characteristic Inventory, had lower average cortisol values and larger testosterone-cortisol ratios than other cadets who did not measure high on these traits. Further, instrumentality and expressiveness traits correlated with effectiveness in dealing with unanticipated stressful events. But, these relationship might not be reliable. The same group of researchers (Sandal, Endresen, Vaernes, & Ursin, 1999) were not able to replicate the relationship between PCI measures and coping strategies with submarine personnel or office workers. And, they found no overall association between personality and physical performance of military-related activities. Measures related to clarity of felt emotions, intensity of felt emotions, and attention to emotional states also show an inconsistent picture. Gohm, Baumann, and Sniezek (2001) reported that clarity correlated significantly negatively with cognitive difficulties during emotion, but that intensity and attention were unrelated to cognitive performance.

We found one well-executed study in which the personality of a leader was shown to influence the performance of followers. Bowles, Ursin, and Picano (2000) reported an assessment of the impact of the captain's personality on

performance and perceived stress in 24 air transport crews. Crews were comprised of 3 members: captain, first officer, and second officer/flight engineer. A total of 72 pilots completed a 1.5-day full-mission simulation of airline operations including emergency situations in a simulator. Three different personality types of captains were defined on the basis of a cluster analysis. Crew members were tested for perceived stress on 4 dimensions of the NASA Task Load Index after each of 5 flight legs. Crews were divided into 3 groups based on rankings from combined error and rating scores. High performance crews (who committed the least errors in flight) reported experiencing less stress in simulated flight than either low or medium crews. When comparing crew positions for perceived stress over all the simulated flights, no significant differences were found. However, the crews led by the "Right Stuff" (e.g., active, warm, confident, competitive, and preferring excellence and challenges) personality-type captains typically reported less stress than crew members led by other personality types. The conclusion is that crews lead by more confident and knowledgeable captains are most likely to function successfully in emergency and other abnormal situations.

Health and Coping Styles

It has generally been accepted by psychologists and physicians that stress is a major factor affecting mental health. In addition, however, in recent years, the role of stress in the development and progression of physical illness and disease has become increasingly clearer. Zakowski, Hall, and Baum (1992) examined the link between stress and health or the ability to combat illness. They reviewed evidence establishing a significant association between several stress situations (i.e., bereavement, depression, marital discord, job loss, examination stress, and chronic non-specific stress) and the state of the human immune system. In addition, they surveyed empirical studies of the health benefits of stress management techniques, including relaxation, cognitive stress reduction, and complex intervention. On the basis of their review, the authors concluded that stress management is a valuable weapon against certain types of disease and physical illnesses and against the progression of diseases already established.

Negative coping style (e.g., venting of negative emotions, denial, task disengagement) is uniquely associated with stress-related health symptoms. Instead of alleviating the adverse outcome of work stressors, negative styles engender high strain and exacerbate the effects of stressors on health symptomatology. Straining is a state of increased motivation aimed at counteracting or overcoming supra-optimal levels of arousal. Straining is known to put the performer at some risk regarding health and/or safety (e.g., Andries, Kompier, & Smulders, 1996). High correlations have been found between work stressors and psychosomatic complaints, general health, and felt fatigue and boredom at work (Houtman, Bongers, Smulders, & Kompier, 1994). The implication of this research is that one should avoid negative coping styles and avoid straining over prolonged periods of work. But this is easier said than done. Formal stress management techniques might be required in some cases.

Occupational stress is a major source of health problems. Work place conditions, both physical and interpersonal, have been shown to lead to negative

emotional reactions (e.g., anxiety), short term (e.g., headaches, stomach distress) and long term (cardiovascular disease) physical health problems and poor on-the-job performance. Ozel (2001) found that time pressure, which is often present in the workplace, increases use of negative coping styles, which in turn threaten health and job performance. Perceptions of control mediate some of these problems. A control-stress model developed by Spector (2002) predicts that, under certain circumstances, enhanced employee control of job elements has a positive influence on health and performance. The idea is that perceived control influences how a potentially stressful event is appraised, the extent to which negative emotions and coping styles are evoked, and the degree of strain on the performer, all of which mediate performance and health.

But the evidence in support of Spector's hypothesis is at best weak. As reported earlier, Endler, et al. (2001) used independent paper and pencil measures of self-efficacy and perceived control of situations to determine which was the better predictor of state anxiety and of performance in cognitive tasks under conditions of stress in both high and low actual control conditions. Self-efficacy was the better predictor of anxiety in both high and low control conditions. But neither self-efficacy nor control predicted performance. So, the self-efficacious are better able to handle stress in so far as felt anxiety is concerned, but, in present circumstances, this does not relate to how well they can do a cognitive task. Results of this sort question the validity of the Spector's (2002) control-stress model.

Bizi, Keinan and Beit-Hallahmi (1988) investigated the role of humor as a means of coping with stress in a training course for Israeli combat noncommissioned officers. Humor as an attribute of each subject was measured both by self-report and by peer-ratings. Degree of success in coping with stress was assessed through ratings by commanders and peers and through final course grades. Findings suggest that humor as rated by peers (but not by self-report) was positively related to performance under stress. Noting that there are two general categories of stress coping strategies: (1) self-generated or active – including

confrontation, fight, and escape, which are evoked when stressors are controllable and escapable, and (2) passive – including quiescence, immobility, and freezing, which are elicited when the stressor is inescapable (Keay & Bandler, 2001), Bizi et al. concluded that the effects of humor were especially strong for active humor (self-produced) as opposed to reactive or passive humor. In a related study, Bhagat, Allie, and Ford (1991) described active problem-solving coping strategies and passive emotion-focused strategies observed in school teachers as they encountered stressful situations in the classroom. Parallel to the results of Bizi et al. (1988) in a different setting, they found that problem solving strategies moderated organizational stress-life strain and personal life stress-life strain relationships to a far greater extent than did emotion-focused coping strategies.

Active and passive coping styles are related to the way in which a performer interprets the task at hand and appraises the stress that it entails. As we have seen, the same task can be appraised as a threat by some individuals and a challenge by others. Larsson (1989) was one of the first researchers to document this difference. As reported earlier, Larsson found that the performance of Swedish military personnel on an artillery simulator degraded and negative coping increased with stress. However, personnel who appraised the task as a challenge demonstrated positive coping and better performance, relative to those who appraised the task as a threat, under all stress conditions.

Wallbott and Scherer (1991) assigned subjects to two groups on the basis of their characteristic approach to dealing with stress. Groups consisted of (a) anxiety denying individuals, who verbally deny their stressful experiences, (b) individuals who are truly low anxiety reactors to stressful conditions, and (c) high anxiety individuals who react strongly and overtly to stressors. These subject types were confronted with both low- and high-arousal-inducing situations, using two different types of stressors, a cognitive stressor (based on the difference between easy and difficult problems to solve) and an emotional stressor (based on the presentation of pleasant or unpleasant slides for viewing). Arousal reactions were measured in two response modalities: verbal report of subjective experience and

physiological reactions. Stress manipulations were effective for all subjects. Physiological indicators were higher in stress conditions for anxiety deniers and for high anxiety subjects, relative to low anxiety subjects. The differences among groups were exacerbated in the cognitive stress as opposed to the emotional stress conditions and were greater for women than for men. The authors claim that coping style clearly mediates not only conscious verbal appraisal of a stressful situation, but also concomitant physiological activity.

Bohnen, Nicolson, Sulon, and Jolles (1991) stressed middle aged and older women with 4 hrs of continuous mental tasks. Performance levels remained fairly steady throughout the session but increasingly and significantly higher cortisol levels were observed over time, in comparison with a control session. Individual variability in cortisol response was high. Correlational data indicate a significant negative relationship between the use of a coping technique that relied on "comforting cognitions" and individual cortisol response during mental stress. Comforting and emotion-focused coping may be effective in this situation because of the subject's efforts to reframe the inevitable situation in a positive and self-encouraging way. There was no significant relationship between trait anxiety and individual GC susceptibility to mental stress.

Conclusions

There is a clear difference between high and low trait anxious subjects on a variety of cognitive tasks. High anxious subjects not only tend to perform more poorly but also are more concrete in the mode of responding. There is some evidence that this difference can be traced to the fact that anxiety might compromise the working memory system. Another effect of anxiety is its tendency to sensitize the individual to threatening or emotional stimuli. Most of the data on trait anxiety and cognition have been collected in the laboratory and there is little evidence to support the extension of these findings to the real world. While there is some promising preliminary evidence from sports psychology, more field studies need to be conducted to determine the extent to which differences between anxious and non-anxious subjects reported above generalize to the real world.

The literature provides little guidance as regards the role of personality traits, other than anxiety, in the stress/performance relationship. It is unclear whether there simply isn't much research being done or whether the results of completed research are so inconclusive or unrevealing with respect that possible relationships that they are not publishable.

In recent years, it has become clear that an association exists between several stress situations (i.e., bereavement, depression, marital discord, job loss, examination stress, and chronic stress) and changes in the human immune system. A negative coping style is uniquely associated with stress related health symptoms. Occupational stress is a major source of health problems. Work place conditions, both physical and interpersonal, have been shown to lead to negative emotional reactions, short term and long term physical health problems, and poor on-the-job performance. Perceptions of control mediate some of these problems.

There are two general categories of stress coping strategies: (1) self-generated or active – including confrontation, fight, and escape, which are evoked when stressors are controllable and escapable, and (2) passive – including quiescence, immobility, and freezing, which are elicited when the stressor is inescapable. Active and passive coping styles are related to the way in which a performer interprets the task at hand and appraises the stress that it entails. Coping style mediates not only conscious verbal appraisal of a stressful situation, but also concomitant physiological activity. Correlational data indicate a significant negative relationship between the use of a coping technique that relied on "comforting cognitions" and individual cortisol response during mental stress.

Stress Countermeasures

Task Conditions

Human beings are extraordinarily adaptive and usually can find ways to adjust to stress even if they cannot completely overcome all of its adverse effects. Slaven and Windle (1999) showed that volunteers for survival training in a disabled submarine did not exhibit any significant performance decrements on reaction time and short-term memory tasks over 7 days. Even though the self-reports of these subjects suggested degraded feeling states, apparently they found ways to compensate in performance for the chronic stress of a relatively severe environment, at least in simple cognitive tasks. Adaptation to chronic stress is apparently quite good, if not prolonged indefinitely.

But there are many demonstrations of both the positive and negative effects of stress on performance, beyond what people can be expected to adapt to. The development of effective training procedures to prepare the individual to resist the negative impact of stress is of considerable interest, not only to the government and military but to all individuals. There has been a fair amount of speculation about what steps might be taken to counteract the effects of stress when they are adverse. But unfortunately, there is relatively little data to support the effectiveness of proposed countermeasures. The countermeasures for which there is the greatest amount of empirical support are those that rely on training in preparation for stressful events. Training that increases automatic processing in standard performance operations under stress has generally been found to be desirable (Kivimaeki, & Lusa, 1994). Empirical evidence for this conclusion comes from Li, Baker, Grabowski, and Rebok (2001). These researcher analyzed data from a large sample of aviation crashes, collected by the National Transportation Safety Board, in an attempt to identify the associated pilot characteristics and crash circumstances. Li et al. found that amount of flight experience was the single most protective factor, reducing pilot error in general aviation crashes. Li et al speculate that training beyond the level of mere mastery

– in other words, overtraining – is an extremely effective antidote against error caused by unexpected stressful events occurring during normal flight operations.

Consistent with this conclusion are the results of Tsang and Voss (1996), who demonstrated that pilot experience was a more important factor than age on a battery of cognitive tasks related to piloting. Other supporting evidence comes from Wiggins and O'Hare (1995), who examined decision-making performance and information acquisition strategies of inexperienced, intermediate, and experienced pilots. Data were obtained from information search patterns and verbal protocols during a series of 6 computer-based simulated flight scenarios. The results revealed significant quantitative and qualitative relationships between the effectiveness of cognitive strategies used and the experience level of pilots. Additional evidence comes from Stokes (1995), who examined the effects of expertise on stressed aeronautical decision making (ADM) performance in a flight simulation task. Novice and expert pilots were administered a battery of cognitive tests, personality tests, and a flight simulation task under stressed and non-stressed conditions. Both groups showed a significant decrement in performance under stress in the non-domain-specific tasks. However, there was no performance decrement in ADM under stress by experienced pilots. Only novice pilots made poorer decisions under stress. Measures of knowledge representation were very predictive of proficient ADM under stress.

But this is about the extent of the evidence. Despite the intuitive appeal of an over-training hypothesis regarding the effects of stress and the fact that many psychologists appear to assume that over-training is the best way to prepare for the adverse effects of stress, there are really very few supporting experimental data. Thus, the study of over-training would appear to be a fruitful area for future research.

Fatigue is an insidious threat to aviation safety because of the impairments in alertness and performance it can create. The fatigue associated with sleep loss, shift work, and long duty cycles, if it persists, can cause aviators to become sloppy,

inattentive, careless, and inefficient, although sometimes performance holds up remarkably well. The only cure for fatigue is adequate sleep; however, gaining sufficient amounts of sleep is often difficult because of work requirements, family demands, or poor sleep habits. Because these conditions are not always easy to change, researchers have examined other possible countermeasures, with varying degrees of success. Caldwell (1997) has argued that pilots can improve their sleep habits and thus gain more restful and restorative sleep by using self-administered relaxation therapy, establishing consistent and soothing bedtime routines, and avoiding certain activities and substances immediately prior to sleep. When opportunities for adequate sleep are not available because of work-related factors, prophylactic naps might sustain performance until sleep is possible.

As noted earlier. Neri, et al. (2002) collected data on breaks and napping in a study of air crews during an uneventful, 6 hr, nighttime simulated flight. They claimed that, in situations that require sustained attention over a prolonged period of time, e.g., during a long overnight flight, brief, regular breaks or naps counteract fatigue and improve alertness, although they have little or no effect on other measures of flight performance. Does it make a difference if a person is required to fill a break with activity? LeDuc, Caldwell, and Ruyak (2000) had volunteer flight personnel engage in 10-min bouts of exercise during one 40-hr period of sleep deprivation. The same subjects rested for an equivalent amount of time during a second deprivation period. Participants were more alert immediately following exercise than after the resting, control condition. However, EEG data collected 50 min following exercise or rest showed that exercise facilitated increases in slow-wave activity, signs of decreased alertness. Cognitive deficits and slowed reaction times associated with sleep loss were equivalent in both conditions. The results from this study suggest that short bouts of exercise may ameliorate some of the increases in sleepiness and fatigue associated with sleep loss for a short period of time but are no more effective than unfilled breaks. Neither exercise nor breaks had a significant effect on the likelihood of errors.

What do pilots think is the best way to counteract the adverse effects of fatigue? Rosenberg and Caine (2001) distributed a survey questionnaire containing background material and Likert-scale questions regarding 14 primary through tertiary fatigue prevention initiatives current in the aero-medical literature to a large number of pilots. The most popular primary prevention initiatives (garnering 87% support) were: (1) requiring pilots to arrive at the squadron at least 3 hrs before night flights to facilitate napping time, and (2) improving scheduling coordination of those air reservists employed as civilian aircrew. The chief (88% support) secondary prevention countermeasure endorsed was to utilize stimulant drugs such as caffeine or amphetamines to sustain the alertness of fatigued aviators. Leading the list of tertiary prevention initiatives (75% support) was the suggestion that squadrons debrief the incidence of aviator fatigue, as well as their success in the area of time-management when debriefing high tempo exercises and operational missions. Thus, at least subjectively, commanders and pilots believed that a wide range of fatigue countermeasures are effective, with the use of stimulant drugs achieving the broadest support.

In support of these survey conclusions, the results of Caldwell (2001) showed that the stimulants, dextroamphetamine or modafinil, have a beneficial effect, relative to a placebo control condition, on performance, subjective mood ratings, and physiological indices of alertness in pilots. Further, Baranski, et al. (2002) reported that a general reduction in cognitive performance on seven different cognitive tasks, caused by 40 hrs of sleep deprivation, was largely eliminated by modafinil. Ramsey and McGlohn (1997) reviewed the literature on the potential of zolpidem as a pharmaceutical against fatigue in US Air Force operations. Results indicate that zolpidem appears to cause less global impairment than benzodiazepines during peak effect, and is free of persistent performance decrement or hangover effect. In fact, few adverse effects have been reported for this stimulant. Several studies suggest a benefit of effective sleep produced by hypnotics on next day performance compared with sleep of questionable quality using no medication. The upshot of available data seems to be that stimulants can

be effective countermeasures against fatigue, as long as drug use is moderate and infrequent and the user is monitored for signs of addiction.

In simple memory and cognitive tasks, Arbuthnott, Geelen, and Kealy (2002) showed that guided imagery can be substituted for real experiences and practice. Similar results have been claimed in sports training. Although there are no data yet available in real life emergency situations, the suggestion is that training might fruitfully include a requirement to imagine emergencies vividly during practice of required responses. Laboratory and sports training results suggest the possibility of positive transfer to performance in real emergency situations.

Under pressure, people are more stressed, anxious, and aroused and more self-conscious about their performance than under normal circumstances. Consequently, they try to exert greater conscious control over their actions, rather than allowing the skills they have acquired to guide their performance implicitly. Beilock and Carr (2001) argue that training in an environment in which one is forced to attend to performance from the outset immunizes the learner against the negative effects of social, competitive, and other pressures. Golfers in a self-monitoring condition were better protected against choking than others because, during training, they had adapted to the impact of conscious self-awareness and were able, unlike participants in the other two conditions, to rely on implicit procedural memories to guide their performance. Without such training, choking is a possible consequence of intense social pressure.

Keinan Friedland, and Sarig-Naor (1990; see also Friedland & Keinan, 1992; Keinan, 1988) compared two basic approaches to phased training (PT) for performance under stress. One approach required that trainees be exposed to stressors of a kind and intensity characteristic of the situations for which they are being trained, including serious physical threats ("high fidelity" training). It has been argued by trainers that such an approach is inappropriate because it suffers from the interference of stressors with skill acquisition. Another approach allowed

trainees to learn in a stress-free environment or under low-intensity stressors ("low fidelity" training). An argument against this approach is that it leaves the trainee insufficiently prepared to perform when stressors first occur. The procedural reinstatement principle of Healy and Bourne (1995) predicts that the first approach will be superior for in-the-field performance and that prediction was sustained by the data. The data are also consistent with those of Beilock and Carr (2001) who found that training under stressors that might occur in the field serves to innoculate performers against choking. However, Keinan et al. (1990) also found that an approach which consisted of three separate and distinct training phases -- a phase which allows the trainee to acquire the task under stress-free conditions, a phase which allows him or her to passively experience the stressor, and a phase in which newly acquired skills are practiced under stress – yielded best transfer performance of all.

Steyvers and Gaillard (1993) speculated that knowledge of results (KR) and rewards could compensate for the negative joint effects of sleep deprivation and signal degradation in a choice-reaction task. The negative effect of signal degradation on performance was aggravated by sleep loss and time-on-task. KR improved performance, especially when signals were degraded. Reward counteracted to some extent the effects of time-on-task owing to lack of sleep. Dutke and Stroebber (2001) have demonstrated that the adverse effects of high stress and anxiety can be compensated for to some degree by enhanced motivation, as might be provided by KR, and by external processing aids. Steyvers and Gaillard (1993) also demonstrated that performance in their task was improved by a brief task interruption after 30 min. work, a result similar to the effects of short breaks on fatigue reported by Neri, et al. (2002).

Following up these results, Becker, Warm, Dember, and Hancock (1995) tested the hypothesis that the adverse effects of stress can be partially offset by supplying the performer with a certain form of augmented feedback on his or her responses. Stress was induced by exposure to intermittent jet aircraft noise occurring during a visual vigilance task. The experiment included six conditions

resulting from factorial combination of 3 levels of noise (high-intensity, low-intensity, and no-noise control) and 2 KR conditions (augmented KR and no KR-control). When compared to subjects performing in quiet, subjects operating in noise were less able to profit from augmented KR. Noise also elevated the perceived workload. Results suggest that stress induced by jet engine noise is not easily attenuated by KR at least in demanding cognitive tasks. In addition, workload elevations engendered by such noise could lead to other negative consequences, such as fatigue, mood changes, and absenteeism. It is difficult to arrange external conditions that countervail such deleterious effects of stress. But Becker et al. (1995) also found that internal conditions (e.g., inducing subjects to try harder) can sometimes effectively offset stress effects, just as Steyvers and Gaillard (1993) had reported.

It has been argued occasionally, but without supporting evidence, that cross-training in a team context for team decision-making under time stress improves overall team performance. In a simulated naval surveillance task, McCann, Baranski, Thompson, and Pigeau (2000) tested the hypothesis that teams whose members explicitly experience all team positions will perform better under time pressure. Further, they posited that experiential cross-training would reduce the negative effect of member reconfiguration that can occur in certain military situations. Three groups of teams (cross-trained [CT], reconfigured, and control) were involved in 3 team training sessions, followed by 3 time-stressed exercise sessions. During training, one group was cross-trained by asking each member to perform an entire session at each of the 3 team positions. Member reconfiguration (where each member was shifted to another's position) was introduced at the first of the exercise sessions for the CT group and for the non-CT reconfigured group. The control group was neither cross-trained nor reconfigured. During training, the performance of non-CT teams improved more quickly than that of CT teams. During the exercise, the CT group did not achieve the level of performance of the control teams. The immediate effect of team member reconfiguration was to degrade performance significantly for the non-CT teams. Thus, cross-training and

reconfiguration degrade rather than improve team performance under stress. Cross-training is not an antidote to stress.

Stress Management

Stress is a fact of life, whether on Earth or in Space, and stress, as we have seen in earlier sections of this report, can have serious adverse effects of human cognition and performance. Stress levels vary with people and situations, but there is hardly anyone who has not experienced significant stress at one time or another. How can we effectively deal with stress? Some people seem to be more successful that others. They might have developed coping strategies on their own for contending with the adverse effects that they might otherwise suffer. But it is also possible to train anyone to manage stress in a more successful manner. Training programs, often called stress management programs (SMPs), have been developed, primarily by clinical psychologists, for this expressed purpose.

Bernier and Gaston (1989) reviewed the literature on a variety of personal SMPs and found that most of them, compared with no treatment, had a beneficial effects on both somatic and cognitive measures of stress. Further, successful completion of a program usually has a lasting effect, improving both immediate and later academic or work performance. Bernier and Gaston reported no differential effectiveness of the various SMPs included in their study, however. In a follow-on, Zakowski, Hall, and Baum (1992) reviewed evidence establishing a significant association between several stress situations (i.e., bereavement, depression, marital discord, job loss, examination stress, and chronic stress) and the state of the human immune system. They then surveyed empirical studies of the health benefits of SMPs, including relaxation therapy, cognitive stress reduction procedures, and certain complex situation-specific interventions. On the basis of their review, the authors concluded that stress management is a valuable weapon not only against temporary interference with performance attributable to stress, but also against certain types of disease and physical illnesses and against

the progression of diseases already established. As with the review of Bernier and Gaston (1989), no differential effectiveness of various SMPs was established.

Still another review of the literature was published by Murphy (1996), who examined the research on the health effects of work-site stress-management interventions. Murphy found 64 major articles published between 1974-1994 covering progressive muscle relaxation, meditation, biofeedback, cognitive-behavioral skills, and combinations of these techniques. Health outcome measures included physiological/biochemical indices, psychological/cognitive tests, and somatic complaints. Job performance and organizational measures were also taken. Over half the studies were randomized control trials, but only a third included post-training follow-up evaluations. Biofeedback was the least frequent technique used in work settings and seemed to be the least effective. Meditation produced the most consistent results across outcome measures but was used in only 6 studies. In general, approaches using a combination of techniques were more effective across outcome measures than single techniques. De Jong and Emmelkamp (2000) found that many SMPs can be effectively administered by paraprofessionals, thus reducing the expense of these training programs that might otherwise be incurred. Moreover, Jason, Curran, Goodman, and Smith (1989) have shown that a televised stress management program, featuring a definition of stress, a description of typical somatic responses to stress, the identification of major life stressors, instruction about social support networks, and demonstrations of behavioral, cognitive, and psychological coping strategies resulted in significant improvement in the adjustment of viewers. Viewers who experienced the most serious life stressors benefited most from the program.

Tallant, Rose and Tolman (1989) evaluated the effectiveness of a stress management treatment based specifically on transactional and group treatment theory. Treatment components included teaching the cognitive-behavioral skills of relaxation, cognitive restructuring, and assertiveness within a structured small-group setting. 32 symptomatic volunteers were assigned to either a treatment group or a wait-list condition. Treatment consisted of 8 2-hr weekly group sessions. On

all dependent measures of stress (including the Profile of Mood States), the treatment subjects evidenced significant pre- to posttest reductions in anxiety, compared to the wait-list controls.

Saunders, Driskell, Johnston, and Salas (1996) reported a meta-analysis to determine the overall effectiveness of stress inoculation training and to identify conditions that may moderate the effectiveness of this approach. The analysis was based on a total of 37 studies, representing the behavior of 1,837 participants. Results indicated that stress inoculation training is an effective means for reducing later performance anxiety and state anxiety, and for enhancing performance under stress. Moreover, an examination of moderators, such as the experience of the trainer, the type of setting in which training was implemented, and the type of trainee population, revealed no significant limitations on the application of stress inoculation training to applied training environments. Like other reviewers of the literature, these authors concluded that all SMPs work to some degree. This conclusion has led some observers to wonder about the extent to which the positive effects obtained from SMPs might be attributable to some sort of Hawthorne or Placebo Effect. Future research will clearly have to address this question.

There are several studies in the recent literature designed to evaluate SMPs that are tied in closely to particular occupations. An example is the work reported by Shipley and Baranski (2002), that used visuo-motor behavior rehearsal as a method to reduce acute anxiety and improve the job performance of police officers. Training employed highly stressful, critical event scenarios involving simulations of life-or-death events and live gun-fire. Trained subjects reported less anxiety and reacted more effectively than untrained control subjects in subsequent test scenarios and in emergency on-the-job situations. Clearly, training for specific emergency situations is useful preparation for job related stressful events. But the generality of these training effects is uncertain. These effects might be limited to the particular training scenarios and the procedures needed to respond to them, as is suggested by the procedural reinstatement principle (Healy & Bourne, 1995).

Follow-on research will be required to determine how broadly pre-training methods will generalize in the job situation.

The recent literature in sports psychology on stress and anxiety, and their management, has been reviewed by Humara (2002). Interestingly, Humara found limited empirical evidence of the effects of anxiety on sports performance, even though these effects seem intuitively clear and there is a great deal of anecdotal literature about them. What data do exist point to a greater role for cognitive anxiety, based on a person's appraisal of the immediate competitive situation, than for somatic anxiety, i.e., physiological arousal components of the competitive situation. The most effective SMPs for sports anxiety are based on cognitive-behavioral therapy, which is consistent with the greater role of cognitive anxiety. Humara finds that these procedures do require a therapist for maximal effectiveness. The goals of therapy, according to Humara, should be (a) to control anxiety on a moment-to-moment basis during competition and (b) to discover a cognitive strategy that optimizes the levels of both cognitive and somatic anxiety. Strategies that have been found to be most successful for controlling stress in sporting events include: Goal-setting, positive thinking about outcomes of competition, situation restructuring where necessary, relaxation, focused attention training, imagery and mental rehearsal.

Crocker (1989) conducted a 6-mo follow-up study of 7 male and 7 female elite volleyball players previously studied in a program that assessed cognitive-affective stress management training. In the follow-up, subjects completed several inventories of sports anxiety during athletic competition. Volleyball service reception performance was the primary performance measure. Findings indicated that both male and female subjects were able to maintain the improved performance levels they had achieved 6 mo. earlier, immediately after SMP training. Women but not men showed significantly reduced anxiety effects in the follow-up, relative to pretreatment or immediate post-treatment. Thus there might be a gender difference in the positive effects of stress management, that reveals itself in feelings of anxiety but not necessarily in performance.

Inzana, Driskell, Salas and Johnston (1996) provided an interesting empirical example of the cognitive control over somatic anxiety created by stress. These authors showed that preparatory information about the stressful nature of a task enhanced later performance in that task (realistic decision making) under high stress conditions, relative to low stress and control conditions. Prepared subjects reported feeling less stressed, were more confident of their ability, and made fewer errors. As noted earlier, Rohrmann, et al. (1999) reported similar data in support of cognitive control of psycho-biological reactions to public speaking stress and, Danboy and Goldstein (1990) showed that how a person appraises potentially stressful situations controls to some degree the emotion these situations engender.

As the foregoing experimental results would suggest, one important component of most cognitive—behavioral stress management programs is the provision of rehearsal opportunities for coping skills. Stress management skills are most effective when people have ample opportunity to practice or rehearse using them in non-stressful, simulated, or imaginary stressful situations (Smith & Nye, 1989). Component analyses of stress inoculation procedures indicate that failure to provide such rehearsal opportunities results in relatively ineffective coping in real-life stress situations, particularly when situational demands are high

Two rehearsal strategies have been used effectively in coping skills training programs. One technique is called covert rehearsal. In this approach, subjects who have been instructed in relaxation and cognitive coping skills imagine themselves applying them to cope with potentially stressful situations. If affective responses occur during an imagined stressful episode, clients are instructed to use their coping skills to reduce them. No attempt is made to generate high levels of affect, since the assumption underlying this inoculation model is that exposure to imagined and low levels of stress helps prepare people to deal successfully with higher levels in the future. The value of covert rehearsal in acquiring cognitive, affect—control, and behavioral skills is well established, whether the focus of imagery involves oneself or models executing adaptive responses.

A different approach emphasizes overt attempts at relaxation under induced affect or emotional arousal. The induced affect, overt rehearsal technique elicits high levels of affective arousal in response to stressful scenes, which can be either real or imagined. Induced affect is designed to allow overt rehearsal of relaxation and cognitive coping responses in the presence of two kinds of cues: (a) external cues that tend to elicit stress responses and (b) internal cues resulting from the emotional arousal process itself. The premise is that learning to control emotionality under these circumstances will facilitate generalization of coping skills across a wide range of stressful situations.

Smith and Nye (1989) compared the effectiveness of covert and overt rehearsal training. Both conditions produced significant reductions in test anxiety, but overt rehearsal yielded a larger test-anxiety decrease than did covert rehearsal, and greater improvement in academic test performance when compared with a control condition. Covert rehearsal, on the other hand, exhibited stronger generalization of treatment effects to a variety of test situations. In the induced-affect condition, improved test performance was highly correlated with reductions in state anxiety. No such relation was found following covert rehearsal, which suggests that the two rehearsal techniques might optimally promote the acquisition and utilization of different classes of coping skills. Where the goal is to develop coping skills specific to a particular context and task, induced affect coupled with overt rehearsal appears to have an advantage both in terms of felt anxiety and performance under stress. Similar strong beneficial effects of overt relaxation exercises have been observed in stressful military tasks by Midgal and Paciorek (1989).

Conclusions

At high enough levels, stress has adverse effects of performance and cognition. There is an extensive literature, spanning basic and applied research, to document these effects. In contrast, unfortunately, there is little empirical data on effective countermeasures to stress. There is considerable speculation, but little that we can be sure about. The best established

countervailing condition is practice or training, or better over-training. The more thoroughly versed in the requirements of a task the performer is, the less the adverse effect of stress. Beyond normal training, training that incorporates exposure to potential stressful events is also useful. When stress arises from prolonged work period and fatigue, stimulant drugs and short period breaks serve as an effective countermeasure. Providing augmented feedback and added extrinsic reward or motivation have been shown to have a positive influence on performance. But some recommended measures, like cross-training of a crew so that all crew members are familiar with the requirements of all tasks, have disappointing effects.

Stress management procedures (SMPs) have been developed, primarily by clinical psychologists, to assist normal people to respond successfully to and in the context of stressful situations. Among the most common procedures are progressive muscle relaxation, meditation, biofeedback, and cognitive-behavioral skills training. There have been many studies assessing and comparing SMPs for their effectiveness. The most effective SMPs are those that depend on relaxation and the acquisition of cognitive-behavioral coping skills. These procedures have been shown to work in various occupations, in academic settings, and in sports. One major component of stress management training focuses on learning proper techniques of appraisal for potentially stressful situations. Both covert and overt rehearsal of stress coping skills have been used with some successful, although the bulk of the evidence suggests that stronger effects are obtained from overt rehearsal. Most survey studies conclude that all SMPs work to some degree. This observation has led some observers to wonder about the extent to which the positive effects observed from SMPs are attributable to some sort of Hawthorne or Placebo Effect

There is some support for the retention of beneficial effects from SMPs over time, but little knowledge exists about their generality. Given recent empirical support for the procedural reinstatement principle, which implies that any training effects are likely to be specific to the circumstances under which training takes place, there is clearly a need for future research on the transfer limitations of SMP training.

Other Reviews of the Literature

There have been other published reviews of the effects of stress on human performance, although none as recent as the one reported here and none that has focused explicitly of the work of cognitive psychologists. We found one of these reviews particularly insightful and useful as a guide to our own search of the

literature. This review appears is a chapter by Orasanu and Backer (1996) in an edited book complied by Driskel and Salas (1996). Orasanu and Backer focus on the combat/military environment and its concomitant stressors. The authors divide stressors into two categories: physical and environmental (sleep deprivation, fatigue, noise, temperature, crowding, isolation) and psychological (threat/danger signals, lack of control, and the individual's perceptions and interpretations of these physical stressors). In describing the military /combat environment in which these stressors occur, the authors comment that the battlefield of the future will likely raise the information processing demands on combatants and that "psychological stressors" will become even more important in dictating the level of performance of individuals. In general, the conclusions regarding stress effects reached by these authors on the basis of their review of the literature are quite similar to and highly consistent with those reported here.

Orasanu and Backer propose certain countermeasures for these two categories of stressors, and review some research on the effectiveness of these countermeasures. The three countermeasures they identify to be of primary importance are Stress Inoculation Training (SIT), skills training, and Crew Resource Management (CRM). SIT is a package that educates the individual about stress and stressors, provides different stress management techniques to learn, and demonstrates the application of preferred techniques to simulated and actual situations. Skills training requires practice under operational conditions before exposure to performance demands in the combat situation, with an emphasis on over-learning. Skills training as a stress reducer is connected to the idea of tasks becoming so well learned that performance becomes "automated" and thereby more resistant to stress. Finally, CRM represents the application of social psychology and management theory to combat team ("crew") interactions. Diverse individuals comprising a crew are trained to share a "mental model" of military operations and problems. Later evidence on the effectiveness of this technique has been weak and inconclusive. But the authors summarize by pointing out that "all 3 techniques can give military personnel a greater sense of control over themselves

and threatening situations--a critical factor in maintaining performance under stress.

Conclusions drawn by the authors are well known to the reader of the present review:
(1) The presence of certain stressors leads to decrements in performance, and to measurable physiological and affective reactions
(2) Different stressors have different effects; there is no such thing as a single "stress reaction"
(3) There are significant variations in the effects of stress on different individuals
(4) Various tasks are differentially vulnerable to various stressors.

Summary and Conclusions

The psychological effects of stress have been measured in various ways, inside and out of the laboratory. These measures fall into three categories, those that rely (1) on neuro-physiological or bodily changes in the individual experiencing stress, (2) on self-report by individuals, and (3) on performance or behavioral changes. Several physiological responses are reliably correlated with the experience of stress and with the occurrence of stressful physical stimuli. One response arises in the autonomic sympathetic nervous system, which controls both neural and hormonal processes. A second principal stress-response system is the brain-pituitary-adrenocortical axis, which regulates the release of glucocortical (GC) hormones into general circulation. Two of the most salient hormonal responses to stress are increases in norepinephrine and cortisol, GCs manufactured and released by the adrenal cortex. A third is the immune system. Although chronic stress typically produces suppression of a wide range of immune system parameters, acute stress has been found to stimulate certain aspects of immune system function.

Measures of physiological responses can serve at least three distinct purposes in research. First, they can help independently to determine the

challenging or stressful character of current circumstances. Second, they permit an assessment of correlations between physiological and cognitive variables. Third, these measures allow the investigation of possible mediating relationships between physiological states and cognitive functioning. To measure physiological reactions to stress, the following procedures seem most useful. First, with respect to the action of the sympathetic nervous system, researchers have examined a variety of peripheral response measures, including, but not limited to, increases in heart rate (HR), blood pressure (BP), respiratory rate, perspiration, and inhibition of digestive and sexual functions. Second, with respect to the brain-pituitary-adrenocortical axis, researchers have measured adrenocortical cortisol in the saliva of human subjects. The immune system cytokine product interleukin-6 (Il-6), which is elevated in response to a variety of stressors, is another marker of stress measureable in saliva.

The most successful self-report measures of stress focus on three processes: (1) commitment to the task, (2) feelings of cognitive overload, and (3) self-assessment of success. Context-induced changes in stress result in patterned shifts in task engagement, distress, and worry on the part of the subject. Patterns are sensitive to task and environmental demands. Comparisons of the value of self-report to neuro-physiological measures of stress have been inconclusive. Most researchers find a high correlation between these two types of measures, leading to the conclusion that, while these measures differ in substantive ways, the information they provide is supplementary and neither is to be preferred over the other. Other researchers have argued that changes in behavioral performance efficiency are the most sensitive reflection of human response to stress, and that behavioral measures should be preferred to both self-report and neuro-physiological measures.

There is no shortage of theories about stress, but, fortunately, there are only a few common themes among these theories. Some theories emphasize the biological consequences of stress, treating behavior as a by-product of biological processes, such as automatic neurological and/or hormonal changes that are

triggered by a stressful event. Others focus on the behavioral consequences of stress and on cognitions that mediate the stress/behavior relationship, including importantly how the "stressful" event is appraised by the organism. In general, theories account for stress effects on cognition and on human performance in terms of multiples of processes. These processes include, but are not limited to: (1) arousal or activation (stress intensity is directly and linearly related to arousal level), (2) resource allocation (stress controls the distribution of mainly attentional resources across points of environmental and internal input and can overload attentional capacity), and (3) plans or strategies. Theories differ in their assumptions about these processes. Some attribute little or no role to consciousness or awareness, asserting that stress effects are direct, automatic, and intuitive. Others assign the major performance control functions to plans, appraisals, analyses, and other cognitive phenomena. No theory completely elucidates the stress process, and it is only reasonable to expect further attempts at theoretical explication in the future.

There is a close relationship between stress and arousal. Stressful events are arousing, causing attendant changes in states of the organism, cognitive processes, and performance. Of greatest relevance to behavior in emergencies are the stress states of (1) strain or mobilization, wherein the person recruits untapped resources to maintain performance levels when arousal is supra-optimal, (2) degradation, wherein mobilization fails and performance suffers but does not fail, (3) choking, wherein performance declines severely and might fail as the organism over-thinks the tasks at hand, and (4) panic, wherein performance reverts to non-cognitive primitive modes of reaction. Research has established the basic parameters of these states, but little is known in detail about situations and individual differences that are conducive to them or about the cognitive difference among states. This is fertile ground for future empirical research.

Anticipation of a stressful event, such as a parachute jump or piloting a plane, often engenders a great deal of uncertainty. Emotions can range from extremely negative (worry, fear, anxiety) to positive (exhilaration, hope,

eagerness). When potentially stressful events are appraised as challenges rather than threats, subjects exhibit better coping styles, more positive emotional feelings, greater confidence about performance, and typically perform better on the task. Because coping styles, appraisals, and emotional feelings are typically measured in these studies in advance of the stressful event, they all appear to have significant roles in mediating or determining performance. But, it is also possible that individuals who are better prepared for a task are more positive about their performance, have more confidence, adopt better coping strategies, and are less likely to see the event as a threat. What is needed to clarify the cause and effect relationships involved here is a technique for experimentally manipulating preparation and appraisal independently, but such a technique has not yet been reported in the literature.

There is a fair amount of agreement in the current literature on appraisal and stress. First, cognitive appraisals play a significant mediating role in biological reactions to stress. Second, performance outcomes depend in part on whether the subject appraises the situation as a challenge or a threat. Third, appraisals tie into coping styles such that challenges are associated with positive and more successful coping styles whereas threats are associated with negative styles. But the picture is not completely clear. It might be that, in all the experimental situations explored to date, more competent people are more likely to view any situations as a challenge rather than a threat. If this is the case, then better coping and better performance naturally follow from challenge appraisals. Because, as yet, no one has been able to create a way of separating conceptually appraisal from competence, we are left with basically a correlational result and without a clear picture of the cause-effect relationships that are involved.

Both chronic anxiety (trait anxious subjects) and acute anxiety (produced by stress or trauma) are associated with a general deficit in a person's ability to inhibit attention to irrelevant stimuli. The effect is most clearly seen when limitations are placed on controlled processing, forcing subjects of rely more heavily on automatic reactions. These results imply that, in a natural emergency or when stress is high,

there is need to be concerned about an operator's ability to focus on the relevant information in the task at hand and to inhibit irrelevant sources of input. This effect of stress on inhibitory processes is similar to and likely related to Easterbrook's conclusion that the range of cues perceived and attended to shrinks under stress or high arousal. The ingestion of stimulants can be effective in offsetting the vigilance decrement as can the aperiodic occurrence of intrusive irrelevant or background stimuli, if they have some degree of alerting function.

A variety of stressful conditions affect memory in a variety of ways, usually but not always adversely. Mandler was one of the first cognitive psychologists to theorize about these effects, attributing them to cognitive resource limitations and to stress-produced noise in the cognitive system. People with high math anxiety have a reduced working memory capacity and, because working memory is required by many arithmetic and mathematical tasks, math anxious subjects perform more poorly on these tasks than low anxious subjects. There is conflicting evidence in the literature regarding memory for emotionally arousing stimuli. Many studies have reported that memory is better for either pleasant or unpleasant material than it is for emotionally neutral material. But there is some evidence that traumatic stimuli, like autopsy photos, can inhibit memory for simultaneously presented neutral material. One study has demonstrated that stress facilitates the formation of false memories.

Elevated cortisol levels have been shown sometimes to have a positive effect and at other times a negative effect on memory. One possible explanation for these conflicting results is that various researchers induced or measured cortisol levels at different points on the Yerkes-Dodson function. When cortisol level is relatively low, on the upward rise of the Y-D function, memory might be facilitated. When cortisol level is beyond the optimum on the Y-D function, performance can be adversely affected. Further complicating the picture is the fact that none of the pertinent experiments has taken account of possible state dependency effects in memory. Thus it is unclear whether the effects of elevated

cortisol, whether facilitative or inhibitory, are the same on encoding and retrieval processes in memory.

Not only does stress affect and often limit memory, but also memories of stressful events can provide a basis for intrusive thoughts, resulting in persistent, protracted, lingering, or chronic stress – a kind of vicious circle. To date, no one has reported on the possible detrimental effects of intrusive thoughts on cognitive task performance in the experimental literature.

There is an extensive experimental literature that examines the influence of stressful environmental conditions on cognitive performance. Despite the common opinion that environmentally imposed time pressure is a major source of stress, surprisingly little research has been reported in recent years that manipulates this variable. Further, the studies that have been reported are quire limited in scope. In general, these studies support the conclusions that time pressure (1) increases errors and response variability in some tasks, (2) shrinks working memory, and (3) reduces cue utilization. The adverse effects of time pressure are strongest on responses that are unfamiliar and/or non-intuitive. But, because the evidence is sketchy, systematic manipulation of time pressure is needed in future research efforts

Workload can get so high that task performance suffers. The adverse effects of overload are related in part to the need to divide attentional resources among the various components of the task to be performed. Especially difficult in these overload conditions is the need to ignore previously relevant task material that, for some reason, is no longer relevant and reorganize the task as a consequence. Probably the most interesting outcome of recent research on workload and overload relates to the manner in which performers handle or adapt to these conditions. Participants can adjust to minor conditions of overload by increased effort or more effective mobilization and deployment of resources. Two strategies of resource deployment have been identified. In some case, the performer can incorporate the response requirements of a secondary task into those of the primary

task, in effect creating one super-task that subsumes both the primary and the secondary. Another strategy is to try to discover ways to relate the stimulus material that one must deal with to already existing knowledge that might not seem in the surface to be relevant.

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Fatigue from prolonged work, work overload, or sleep deprivation causes feelings of stress and, in some cases, degrades performance. A sometimes-observed speed-accuracy trade-off in fatigue states illustrates two important caveats concerning the effects of stressors on performance. First, stress effects may be different for different measures. Second, the effects of stressors may not always be harmful. One stressor might actually facilitate response times and simultaneously inhibit accuracy. Under some circumstances, fatigue has latent effects that only show up after sufficient passage of time. Further, recovery from fatigue requires rest and time away from task. The effects of fatigue might be attributable in part to reductions in controlled processing. Incentives have been successfully used to increase controlled processing, effectively counteracting the effects of fatigue.

Well-trained performers seem to acquire coping strategies that allow them to maintain stable performance levels when long work sessions are of known duration and do not exceed 12 hrs. Cognitive effects of stress appear to be ameliorated by knowledge that the stressful situation, although long, is time limited. Insufficient sleep, combined with rotating schedules and other work demands, no doubt contributes to the perception that fatigue is a widespread problem in the aviation community. Fatigue-reduction strategies should be an important component of training and operational environments. For example, in situations that require sustained attention over a prolonged period of time, e.g., during a long overnight flight, brief, regular breaks improve alertness and performance. Sometimes stimulating drugs can be effective in improving performance, subjective mood ratings, and physiological indices of alertness.

Effects on cognition attributable to environmental or workplace noise are complex and not presently well-understood. There is no truly comprehensive experiment on noise that has yielded unambinguous results. The effects of noise, although typically negative, can be overcome by increased effort and by time spent outside the noisy environment. What is needed to resolve the uncertainty in results of presently available studies and to examine the effects of noise pollution on performance is a single coherent experiment in which noise intensity and duration are systematically varied as subjects perform a range of cognitive tasks.

Intense environmental heat or cold in natural or in laboratory circumstances can have an adverse effect both on behavior and on correlated brain processes. Some performance effects can be offset by extra effort, but if heat (or cold) conditions persist, performance eventually suffers. The best recommendation one can make on the basis of the available data is to try to keep ambient temperature near optimal for the given task and individual.

Isolation and confinement are stressful, but have surprisingly little adverse effect of performance in a variety of tasks. If participants are well-prepared and understand that their confinement and isolation is time-limited, performance holds up well, although mood can swing quite widely. Prolonged hypoxia, in contrast, degrades some aspects of cognitive functioning, especially those that emphasize speed of response. An acclimation protocol based on intermittent exposure to simulated high altitudes can be used to offset these effects.

There is a clear difference in performance of high and low trait anxious subjects on a variety of cognitive tasks. High anxious subjects not only tend to perform more poorly but also are more concrete in their mode of responding. There is some evidence that this difference can be traced to the fact that anxiety might compromise the working memory system. Another effect of anxiety is its tendency to sensitize the individual to threatening or emotional stimuli. Most of the data on trait anxiety and cognition have been collected in the laboratory, and there is little evidence to support the extension of these findings to the real world.

Field studies need to be conducted to determine the extent to which differences between anxious and non-anxious subjects reported from the laboratory generalize to the real world. A review of the literature in sports psychology reveals some promising similarities between laboratory outcomes and performance in various forms of sporting events. But there are too few data available presently to support strong conclusions. Other than individual differences in anxiety, personality traits appear not to have been studied extensively for their relationship to performance under stress.

In recent years, it has become clear that an association exists between several stress situations (i.e., bereavement, depression, marital discord, job loss, examination stress, and chronic stress) and changes in the human immune system. A negative coping style (e.g., venting of negative emotions, denial, task disengagement) is uniquely associated with stress related health symptoms. Occupational stress is a major source of health problems. Work place conditions, both physical and interpersonal, have been shown to lead to negative emotional reactions (e.g., anxiety), short term (e.g., headaches, stomach distress) and long term (e.g., cardiovascular disease) physical health problems, and poor on-the-job performance. Perceptions of control, or lack thereof, mediate some of these problems.

There are two general categories of stress coping strategies: (1) self-generated or active – including confrontation, fight, and escape, which are evoked when stressors are controllable or escapable, and (2) passive – including quiescence, immobility, and freezing, which are elicited when the stressor is inescapable. Active and passive coping styles are related to the way in which a performer interprets the task at hand and appraises the stress that it entails. As noted previously, the same task can be appraised as a threat by some individuals and a challenge by others. Coping style mediates not only conscious verbal appraisal of a stressful situation, but also concomitant physiological activity. Correlational data indicated a significant negative relationship between the use of a coping technique

that relied on "comforting cognitions" and individual cortisol response during mental stress.

Although there is an extensive literature, spanning basic and applied research, to document the adverse effects of stress on cognition and performance, there is, in contrast, little empirical data on effective countermeasures to stress. Speculation abounds, but little that we can be sure about. The best established countervailing effect derives from practice or training, or better over-training. The more thoroughly versed in the requirements of a task the performer is, the less the adverse effect of stress. Beyond normal training, training that incorporates exposure to potential stressful events is also useful. When stress arises from prolonged work period and fatigue, stimulant drugs and short period breaks serve as an effective countermeasure. Providing augmented feedback and added extrinsic reward or motivation have a positive influence on performance. But some recommended measures, like cross-training of a crew so that all crew-members are familiar with the requirements of all tasks, have disappointing effects.

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the extent to which the positive effects observed from SMPs are attributable to some sort of Hawthorne or Placebo Effect

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13. ABSTRACT *(Maximum 200 words)*

Research in cognitive psychology has made a significant contribution to our understanding of how acute and chronic stress affect performance. It has done so by identifying some of the factors that contribute to operator error and by suggesting how operators might be trained to respond more effectively in a variety of circumstances. The major purpose of this paper was to review the literature of cognitive psychology as it relates to these questions and issues. Based on the existence of earlier reviews (e.g., Hamilton, & Warburton, 1979; Hockey, 1983) the following investigation was limited to the last 15 years (1988–2002) and restricted to a review of the primary peer-reviewed literature. The results of this examination revealed that while cognitive psychology has contributed in a substantive way to our understanding of stress' impact on various cognitive processes, it has also left many questions unanswered. Concerns about how we define and use the term stress and the gaps that remain in our knowledge about the specific effects of stressors on cognitive processes are discussed in the text.

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