Stress and cognition

Health & Medicine, Stress

Stress and Cognition Final Report STRESS AND COGNITION: A COGNITIVE PSYCHOLOGICAL PERSPECTIVE National Aeronautics and Space Administration Grant Number NAG2-1561 Lyle E. Bourne, Jr. and Rita A. Yaroush February 1, 2003 1 Stress and Cognition 2 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 Stress and Cognition 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 3 Stress and Cognition 4 Stress and Cognition: A Cognitive Psychological Perspective Lyle

E. Bourne, Jr. and Rita A. Yaroush University of Colorado 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 Stress and Cognition 5 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 dynamic, 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 time-dependent, because decisions must be made at the correct moment in relation to environmental demands. Emergencies tend to be complex, in the sense that most variables are not related to each other in one-to-one manner. Finally, emergencies are stressful, 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 Stress and Cognition 6 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 Stress and Cognition 7 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 Stress and Cognition 8 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 crewmembers 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 Stress and Cognition 9 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 Stress and Cognition 10 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. Stress and Cognition 11 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. An Example 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, Stress and Cognition 12 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 Stress and Cognition 13 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 in the early part of the 20th century. 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 Stress and Cognition 14 “ 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 stressinduced 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 Stress and Cognition 15 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 stressreactive 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 Stress and Cognition 16 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 (Il6), 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 Stress and Cognition 17 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 Stress and Cognition 18 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 t hree p rincipal a daptive c hallenges p osed b y s tressful p erformance 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 t he b est i nstrument a vailable. I f s tress m easures a re r equired 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. Stress and Cognition 19 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. 1. Delineate and focus on those actions and problems that are subject to operator control. 2. 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. 3. Design the system with stress factors in mind. For example, avoid overload on operator controlled tasks. 4. 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 Stress and Cognition 20 (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 Stress and Cognition 21 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 selfreports 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. Conclusions1 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. 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. Stress and Cognition 22 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 brainpituitary-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 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 Stress and Cognition 23 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 multitasking 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 Stress and Cognition 24 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. Cognitive Continuum Theory. 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 Coherence 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 Correspondence 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 analytical cognition (deliberate cognitive processes) and the second approach emphasizes intuitive cognition (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 and cognitive properties. Stress and Cognition 25 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 COGNITIVE INDEX INTUITIVE QUASIRATIONAL ANALYTIC TASK CONTINUUM INDEX INTUITIVE QUASIRATIONAL Best 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