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TASK LOADING AND STRESS IN HUMAN-COMPUTER INTERACTION: THEORETICAL FRAMEWORKS AND MITIGATION STRATEGIES

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TASKS AS STRESSORS: THE CENTRALITY OF STRESS IN HUMAN-COMPUTER INTERACTION

For those whose professional lives revolve around human-computer interaction (HCI), they may ask themselves why they should even glance at a chapter on stress. While it is evident that many computer systems have to support people operating in stressful circumstances, there are important design issues concerning how to present information in these very demanding circumstances. However, one could still ask, are these of central interest to those in the mainstream of HCI? Indeed, if these were the only issues, we would agree and would recommend the reader to pass quickly onto something of much more evident relevance. However, we hope to persuade you that the relevance of stress research to HCI is not limited to such concerns. Indeed, we hope to convince the reader that stress, in the form of task loading, is central to all HCI. To achieve this, we first present a perspective that puts stress front and center in the HCI realm. Traditionally, stress has been seen as exposure to some adverse environmental circumstances, such as excessive heat, cold, noise, vibration, and so forth, and its effects manifest themselves primarily in relation to the physiological system most perturbed by the stress at hand. However, Hancock and Warm (1989) observed that stress effects are virtually all mediated through the brain, but for the cortex such effects are almost always of secondary concern since the brain is primarily involved with the goals of ongoing behavior or, more simply, the current task. Therefore, we want to change the orientation of concern so that stress is not just a result of peripheral interference but rather that the primary source of stress comes from the ongoing task itself. If we now see the task itself as the primary driving influence then stress concerns are central to all HCI issues.

It is one of the most evident paradoxes of modern work that computer-based systems, which are designed to reduce task complexity and cognitive workload, actually often impose even greater demands and stresses on the very individuals they are supposed to be helping. How individuals cope with such stress has both immediate and protracted effects on their performance and well-being. Although operational environments and their associated tasks vary considerably (e.g., air traffic control, baggage screening, hospital patient monitoring, power plant operations, command and control, and banking and finance), there are certain mechanisms that are common to the stress appraisal of all task demands. Thus, there are design and HCI principles for stress that generalize across multiple domains (Hancock & Szalma, 2003a). In this chapter we explore such principles to understand stress effects in the HCI domain.

The structure of our chapter flows from these fundamental observations. First, we provide the reader with a brief overview of stress theory and its historical development to set our observations in context. Second, we articulate areas for future research needed to more completely understand how stress and workload impact human-computer interaction and how to exploit the positive effects while mitigating their negative effects.

TRADITIONAL APPROACHES TO STRESS RESEARCH

Traditionally, stress has been conceived of as either (a) an external, aversive stimulus (constituted of either physical, cognitive, or social stimulation patterns) imposed upon an individual or (b) response to such perturbations. Each of these views presents certain intrinsic operational difficulties. Considering stress as external stimulation is useful for categorizing effects of the physical environments (e.g., heat, noise, vibration), but such an approach cannot explain why the same stimulus pattern has vastly different effects on different individuals. Physiological interpretations (e.g., Selye, 1976) have tried to promulgate arousal explanations of stress. However, the more recent recognition that different sources of stress are associated with different patterns of cognitive effects made clear that adaptation or arousal theories of stress do not completely address the issue either (Hockey, R., 1984; Hockey, R. & Hamilton, 1983; Hockey, G. R. J., Gaillard, & Coles, 1986).

Thus to understand stress effects, we now have to embrace an even wider, multidimensional perspective (e.g., Matthews, 2001). Here we emphasize a view of stress as primarily an outcome of the appraisal of environmental demands as either taxing or exceeding an individual's resources to cope with that demand. These person-environment transactions (Lazarus & Folkman, 1984) occur at multiple levels within the organism (Matthews, 2001; van Reekum & Scherer, 1997). Further, these processes represent efforts by organism to adapt to demands imposed via regulation of both the internal state and the external environment. In the following section, we describe the theoretical frameworks that guide our observations on HCI. These perspectives emerge from the work of Hancock and Warm (1989), G. R. J. Hockey, (1997), and Lazarus (1999; see also Lazarus & Folkman, 1984).

THEORETICAL FRAMEWORKS

Appraisal Theory

Among the spectrum of cognitive theories of stress and emotion, perhaps the best known is the relational theory proposed by Richard Lazarus and his colleagues (see Lazarus, 1991, 1999; Lazarus & Folkman, 1984). This theory is cognitive in that stress and emotion each depend upon an individual's cognitive appraisals of internal and external events, and these appraisals depend in part on the person's knowledge and experience (cf., Bless, 2001). The theory is motivational in that emotions in general, including stress responses, are reactions to one's perceived state of progress toward or away from one's goals (see Carver & Scheier, 1998). The relational aspect emphasizes the importance of the transaction between individuals and their environment. Together these three components shape the emotional and stress state of an individual. The outcomes of these processes are patterns of appraisal that Lazarus (1991) referred to as "core relational themes." For instance, the core relational theme for anxiety is uncertainty and existential threat, while that

for happiness is evident progress toward goal achievement. Thus, when individuals appraise events relative to their desired outcomes (goals), these can produce negative, goal-incongruent emotions and stress if such events are appraised as hindering progress. Conversely, promotion of well-being and pleasure occur when events are appraised as facilitating progress toward a goal (e.g., goal-congruent emotions). Promotion of pleasure and happiness (see Hancock, Pepe, & Murphy, 2005; Ryan & Deci, 2001) therefore requires the design of environments and tasks themselves that afford goal-congruent emotions. The understanding of interface characteristics in HCI which facilitate positive appraisals and reduce negative appraisals is thus a crucial issue and an obvious avenue in which HCI and stress research can fruitfully interact.

A major limitation of all appraisal theories, however, is the neglect of understanding how task parameters influence resulting coping response. While the appraisal mechanism itself may be similar across individuals and contexts (e.g., see Scherer, 1999), the specific content (e.g., which events are appraised as a threat to well-being) does vary across individuals and contexts. One would expect that the criteria for appraisal (e.g., personal relevance, self-efficacy for coping) would be similar across individuals for specific task parameters as for any other stimulus or event. Individual differences occur in the specific content of the appraisal (e.g., one person's threat is another's challenge) and in the resultant response. An understanding of stress effects in HCI therefore requires understanding the task and person factors, and treating the transaction between the human and the system as the primary unit of analysis (see Lazarus & Folkman, 1984). This entails knowing how different individuals appraise specific task parameters and how changes in knowledge structures might ameliorate negative stress effects and promote positive affect in human-technology interaction. A visual representation of this emergent unit of analysis that comes from the interaction of person and environment, including the task, is shown in Fig. 6.1 (Hancock, 1997).

Adaptation Under Stress

A theoretical framework developed specifically for stress as it relates to performance is the maximal adaptability model presented by Hancock and Warm (1989). They distinguished the three facets of stress distinguished above, and they labeled these the trinity of stress, shown in Fig. 6.2. The first, "Input," refers to the environmental events to which the individual is exposed which include information (e.g., displays) as well as traditional input categories such as temperature, noise, vibration, and so forth (e.g., Conway, Szalma, & Hancock, 2007; Hancock, Ross, Szalma, in press; Pilcher, Nadler, & Busch, 2002). The second, "Adaptation," encompasses the appraisal mechanisms referred to previously. The third and final component, "Output," is the level which indicates how the organism behaves in respect to goal achievement. A fundamental tenet of the Hancock and Warm (1989) model is that in the large majority of situations (and even in situations of quite high demand) individuals do adapt effectively to the input disturbance. That is, they can tolerate high levels of either overload or underload without
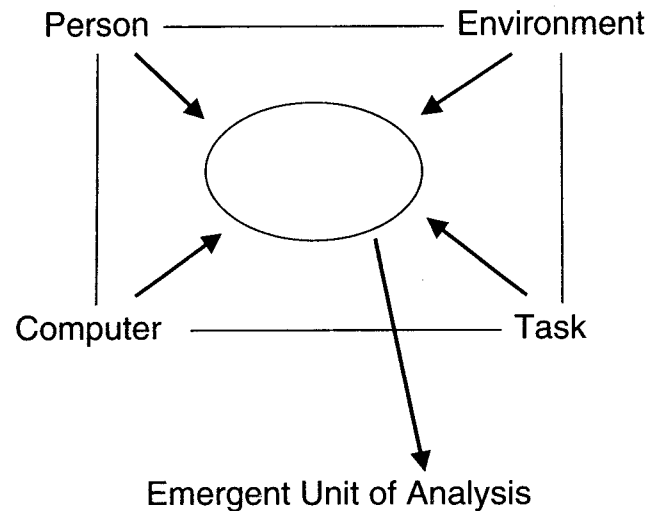

FIGURE 6.1.   An illustration of the emergence of a supra-ordinate unit of analysis that derives from the interaction of the individual (person, the tool they use (computers), the task they have to perform, and the context (environment) in which action occurs. From Hancock 1997)
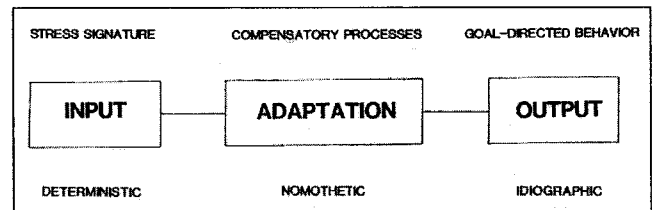

FIGURE 6.2.   The trinity of stress which identifies three possible 'loci' of stress. It can be viewed as an *input* from the physical environment which can be described deterministically. Since such a profile is by definition unique, it is referred to as a stress signature. The second locus is *adaptation*, which describes the populational or nomothetic reaction to the input itself. It is most evidently measurable in the processes of compensation. The third and final locus is the *output* which is expressed as the impact on the on-going stream of behavior. Since the goals of different individuals almost always vary, this output is largely idiographic or person-specific. It is this facet of stress which has been very much neglected in prior and contemporary research. From Hancock and Warm (1989)

enormous change to their performance capacity. Adaptive processes occur at multiple levels, some being the physiological, behavioral (e.g., performance), and subjective/affective levels. These adaptations are represented in the model as a series of nested, extended, inverted-U functions (see Fig. 6.3) that reflect the fact that under most conditions the adaptive state of the organism is stable. However, under extremes of environmental underload or overload, failures in adaptation do occur. Thus, as the individual is perturbed by the input, the first threshold they traverse is subjective comfort. This is followed by behavioral effects, and finally failure of the physiological system (e.g., loss of consciousness). Examples of such extreme fail-
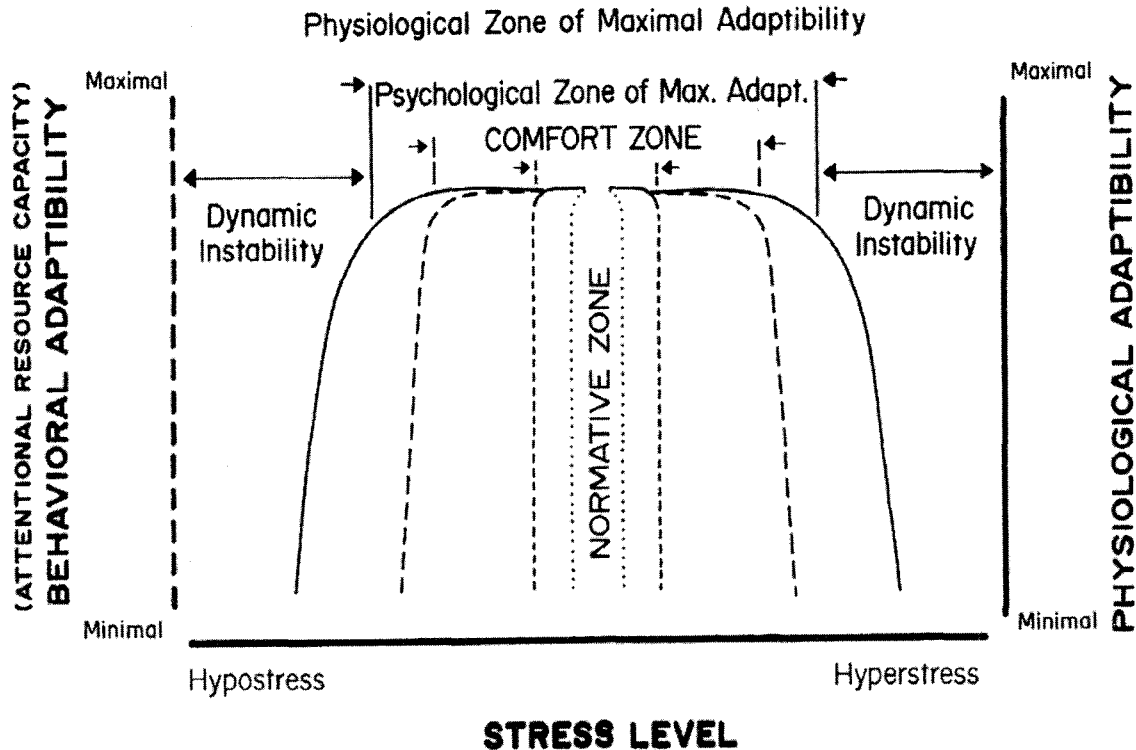
Physiological Zone of Maximal Adaptibility

FIGURE 6.3. The extended-U relationship between stress level and response capacity. As is evident, the form of degradation is common across the different forms of response. At the center of the continuum is the normative zone which reflects optimal subjective functioning. Outside of this is the comfort zone which reflects the behavioral recognition of a state of satisfaction. Beyond this lies the reaction of psychological or cognitive performance capacity. Finally, the outer envelope is composed of physiological functioning. There are proposed strong linkages between the deviation from stability at one level being matched to the onset of radical failure at the more vulnerable level which is nested within it. The model is symmetrical in that underload (hypostress) has mirror effects to overload (hyperstress). The latter is considered the commonly perceived interpretation of stress. From Hancock and Warm (1989)

ures are relatively rare in most work settings, although when they do occur they are often catastrophic for the individual and the system they are operating (e.g., Harris, Hancock, & Harris, 2005).

This model is unique in that it provides explicit recognition that the proximal form of stress in almost all circumstances is the task itself. Task characteristics are incorporated in the model by two distinct base axes representing spatial and temporal components of any specified task. Information structure (the spatial dimension) represents how task elements are organized, including challenges to such psychological capacities such as working memory, attention, decision making, response capacity, and the like. The temporal dimension is represented by information rate. Together these dimensions can be used to form a vector (see Fig. 6.4) that serves to identify the current state of adaptation of the individual. Thus, if the combination of task characteristics and an individual's stress level can be specified, a vector representation can be used to predict behavioral and physiological adaptation. The challenge lies in quantifying the information processing components of cognitive work (see Hancock, Szalma, & Oron-Gilad, 2005).

Although the model shown in Fig. 6.4 describes the level of adaptive function, it does not articulate the mechanisms by which such adaptation occurs. Hancock and Warm (1989) argued that one way in which individuals adapt to stress is to narrow their attention by excluding task irrelevant cues (Easterbrook, 1959). Such effects are known to occur in spatial perception (e.g., Bursill, 1958; Cornsweet, 1969), and narrowing can occur at levels of both the central and peripheral neural systems (Dirkin & Hancock, 1984; 1985; Hancock & Dirkin, 1983). More recently Hancock and Weaver (2005) argued that distortions of temporal perception under stress are also related to this narrowing effect. However, recent evidence suggests that these two perceptual dimensions (space and time) may not share common perceptual mechanisms (see Ross, Szalma, Thropp, & Hancock, 2003; Thropp, Szalma, & Hancock, 2004).

The Cognitive-Energetic Framework

The Hancock and Warm (1989) model accounts for the levels of adaptation and adaptation changes under the driving forces
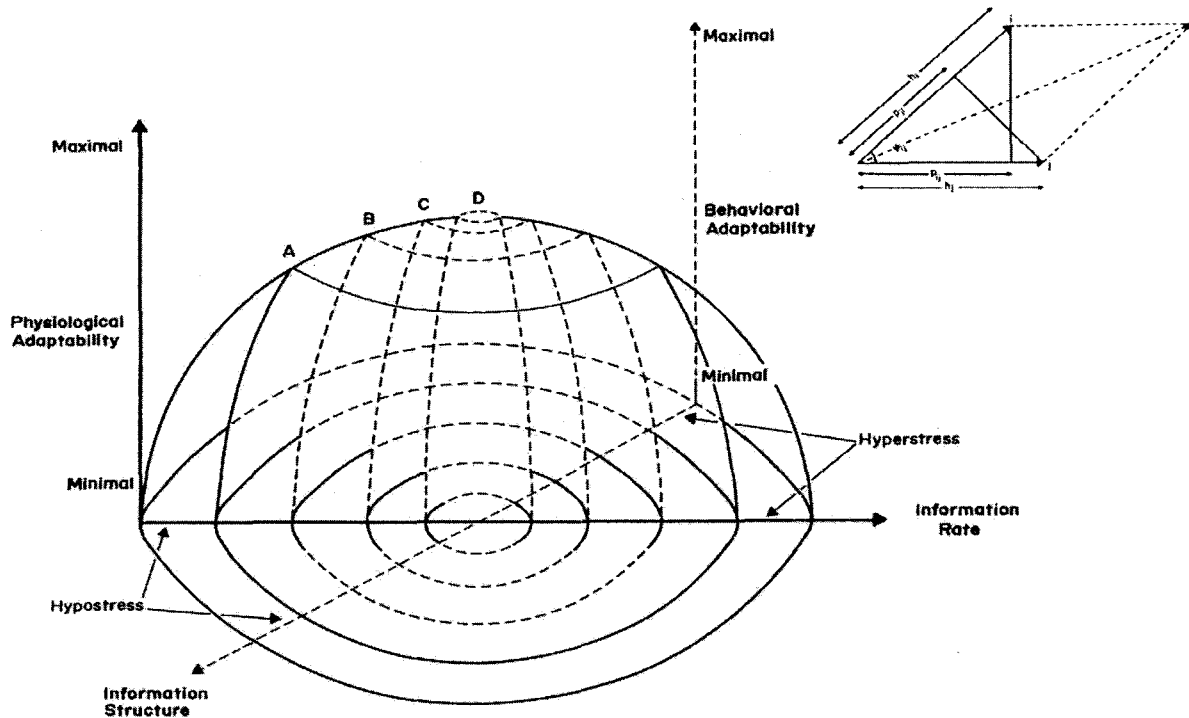
FIGURE 6.4. The description given in Figure 6.3 is now expanded into a three-dimensional representation by parsing the base "hypostress-hyperstress" axis into its two component elements. These divisions are compose of information rate (the temporal axis) and information structure (the spatial axis). Note that any one source of input stress can be described as a scalar on the base axis and these scalars can be summed to provide a multi-input stress vector which then provides a prediction of both performance and physiological adaptability which are the primary descriptors on the vertical axis. From Hancock and Warm (1989)

of stress. However, it does not articulate how effort is allocated under stress or the mechanisms by which individuals appraise the task parameters that are the proximal source of stress. The effort allocation issue is address by a cognitive-energetical framework described by G. R. J. Hockey (1997). The compensatory control model is based upon three assumptions: behavior is goal directed; self-regulatory processes control goal states; and regulatory activity has energetic costs (e.g., consumes resources). In this model a compensatory control mechanism allocates resources dynamically according to the goals of the individual and the environmental constraints. The mechanisms operate at two levels (see Fig. 6.5). The lower level is more or less automatic and represents established skills. Regulation at this level requires few energetic resources or active regulation and effort (cf., Schneider & Shiffrin, 1977). The upper level is a supervisory controller which can shift resources (effort) strategically to maintain adaptation and reflects effortful and controlled processing. The operation of the automatic lower loop is regulated by an effort monitor, which detects changes in the regulatory demands placed on the lower loop. When demand increases beyond the capacity of the lower loop control is shifted to the higher, controlled processing loop. Two strategic responses of the supervisory system are increased effort and changing the goals. Goals can be modified in their kind (change the goal
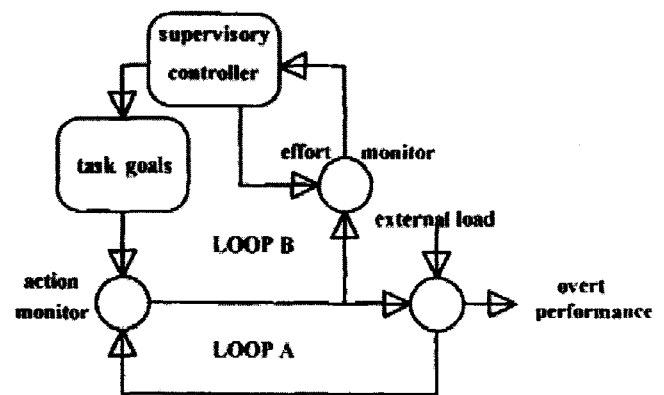
FIGURE 6.5. The two-level effort regulation model by Hockey. This model provides a mechanism by which an individual allocates limited cognitive resources to different aspects of performance. From Hockey (1997).

itself) or in strength (e.g., lowering the criterion for performance). Essentially, this is adjusting the discrepancy between goal state and current state by increasing effort or changing the goal (and see Carver & Scheier, 1998).

RELATIONSHIP BETWEEN STRESS AND COGNITIVE WORKLOAD

Cognitive Workload as a Form of Stress

The Hancock and Warm (1989) model explicitly identified the task itself as the proximal source of stress. In operational environments, this is often manifested as increases or decreases in cognitive workload (Moray, 1979). As in the case of stress, workload is easy to define anecdotally but difficult to define operationally. Workload can manifest in terms of the amount of information to be processed (an aspect of information structure), and the time available for processing (information rate). Thus, the base axes of the Hancock and Warm model captured dimensions of workload as well as stress (see Hancock & Caird, 1993). Indeed, physiological measures of workload (O'Donnell & Eggemeier, 1986) are often the same as those measures used to assess physiological stress. Similarly, subjective measures of workload and stress reflect appraisals of the task environment and of its perceived effect on the individual (Hart & Staveland, 1988). Although the two concepts developed in separate research traditions, the artificial boundary between them should be dissolved, as each term refers to similar processes. The implication for HCI is that computer-based tasks that impose either too much or too little demand will likely be appraised as stressful. Thus, the design process for development of computer interfaces should include assessment of perceived workload as well as affective state.

Performance and Workload: Associations/Dissociations

It is often the case that performance is maintained under increased workload and stress, which is reflected in the extended-U model described by Hancock and Warm (1989) and in the mechanisms of Hockey's (1997) energetic model of compensatory control. Maintaining performance under stress has costs, both physiologically and cognitively. Further, one would expect that in easier tasks performance is not as costly and that there should therefore be a direct association between task difficulty and perceived workload. Such performance-workload associations do occur, most prevalently in vigilance (Warm, Dember, & Hancock, 1996; see also Szalma et al., 2004). However, other forms of workload-performance relations can occur. For instance, perceived workload may change as a function of changes in task demand, but performance remains constant. Hancock (1996) referred to these situations as "insensitivities," which can be diagnostic with respect to the relation between the individual and the task (see also Parasuraman & Hancock, 2001). Thus, consistent with both Hancock and Warm and G. R. J. Hockey's (1997) frameworks, one response to increased task demand is to exert more effort, thereby maintaining performance but increasing perceived workload. Alternatively, one could have a situation in which task demands increase, performance decreases, but perceived workload does not change. This suggests that the appraisals of the task are not sensitive to actual changes in that task.

Interesting corollaries are the performance-workload dissociations that sometimes occur (Hancock, 1996; Yeh & Wickens, 1988). In such cases, decreased performance is accompanied by decreased workload. One possible reason for such a result might be disengagement of the individual from the task (e.g., the person gives up; see Hancock, 1996). In the case where increased performance is observed to be accompanied by increased perceived workload, the pattern suggests effective improvement of performance at the cost of increased effort allocation. An area of much needed research is establishing which task parameters control the patterns of performance-workload associations and dissociations, and how these change dynamically as a function of time on task. It may well be that reformulating the task by innovations in the interface itself may well address these crucial concerns (see Hancock, 1997). Indeed, the structure and organization of computer interfaces will be a major factor in both performance under stress and in the relation of performance to perceived workload.

MITIGATION OF STRESS

If changing the fundamental nature of the demand is one solution, we now look at other approaches to mitigation of the negative effects of stress and workload. These strategies include skill development (e.g., Hancock, 1986), and specific display design (Hancock & Szalma, 2003a; Wickens, 1996), as well as technologies employing adaptive automation and decision aids (Hancock & Chignell, 1987). Developing skills so that they are relatively automatic rather than controlled processing (Schneider & Shiffrin, 1977) and developing expertise can mitigate some of the negative effects of stress. In regard to display design, simple, easily perceivable graphics can permit quick, direct extraction of information when cognitive resources are reduced by stress and workload (Hancock & Szalma, 2003a). Adaptive automation can be employed by adjusting the level of automation and the management of automation according to stress state (e.g., Scerbo, Freeman, & Mikulka, 2003). In addition, adapting the form of automation (e.g., level, management type) to the operator based on individual differences can serve to improve its utility for aiding performance and reducing stress and workload (see Thropp, Oron-Gilad, Szalma, & Hancock, 2007).

Changing the Person

Training/skill development. Clearly, the greater the skill of the individual the more resilient their performance will be under stress (Hancock, 1986). This well-established phenomenon is incorporated into the energetic theories of stress and performance (Hancock & Warm, 1989; Hockey, 1997) and is an approach most often taken to mitigate workload and stress effects. However, training on relevant tasks is only one method of training for stress. There are also techniques for training individuals to cope more effectively with stress, essen-

tially building stress coping skills. An example of such an approach is stress exposure training (SET; Johnston & Cannon-Bowers, 1996), a three phase procedure in which individuals are provided with information regarding the stress associated with task performance, are provided with training on the task, and then practice their task skills under simulated stress conditions. This technique has been shown to be effective in reducing anxiety and enhancing performance (Saunders, Driskell, Johnston, & Salas, 1996) and there is preliminary evidence that coping skills learned with a particular type of stressor and task can transfer to novel stressors and tasks (Driskell, Johnston, & Salas, 2001). For such an intervention to succeed, however, it is crucial that the training be designed based on an analysis of the task environment (Johnston & Cannon-Bowers, 1996). If the task parameters that are most responsible for the workload and stress are identified, these can be targeted for attention in training.

An additional issue for training for more effective stress coping is to modify the individual's appraisal of events. By inducing automaticity in some skills, not only are more resources freed for stress coping, but the task environment itself will be appraised as less threatening. Even if the event is appraised as a threat to an individual's psychological or physical well-being, the highly skilled individual will appraise his or her coping ability as sufficient to handle the increased demand. However, there has been limited research on how individuals who develop expertise also develop the capacity to effectively cope with the stress that accompanies performance in a given domain, and the extent to which stress coping skills in one domain transfer to other domains. Deliberate practice generally facilitates skill development (Ericsson, 2007). If one considers coping with stress to be a skill, then in principle deliberate practice should permit the development of expertise in coping. This will likely involve parsing the task into components, based on cognitive task analysis, and designing training procedures that target the stressful aspects of the task. However, such efforts will require understanding of how different forms of stress affect different forms of information processing. Since these variables are difficult to quantify, establishing these linkages must be theory driven. Elucidation of these issues will provide the groundwork for future development of stress mitigation tools during training and skill development.

Personnel selection. Selection techniques have been a popular choice for matching individuals to specific jobs, but the focus has typically been on intellectual skills (e.g., Yerkes, 1918). Selecting individuals for their stress-coping capability has been applied to the selection criteria for police officers, who therefore tend to be as stable as or more emotionally stable than the rest of the population (for a review, see Brown & Campbell, 1994). However, research is needed that links particular traits to stress coping skills for specific task environments. The effectiveness of general life stress coping, such as that observed in individuals who are extraverted (McCrae & Costa, 1986; Penley & Tomaka, 2002) or optimistic (Aspinwall, Richter, & Hoffman, 2002; Scheier & Carver, 1985), may not predict effective coping in specific task domains. Understanding which individuals will likely cope effectively with a particular task therefore requires a thorough understanding of the perceptual, cognitive, and psychomotor demands of the task, and then linking these parameters to trait profiles. By far, the most research on the relation of affective traits to task performance has been in Extraversion and trait anxiety/Neuroticism (for a review, see Matthews, Deary, & Whiteman, 2003). However, the characteristics of greatest interest may vary somewhat across domains, although some general traits (e.g., emotional stability, conscientiousness) would be expected to moderate performance across a variety of task environments.

Changing the Task

Display design. Although training and selection can mitigate stress effects, the tasks themselves should be redesigned, for two reasons. First, there will be many instances where selection is not possible and expenditure of significant resources on training is undesirable. Second, there are instances in which one wishes to design an interface that requires little or no training and that can be used by any member of a large population of individuals (e.g., consumers). Particularly in light of the observation that the task represents the proximal source of stress, future work in stress mitigation for HCI should focus on redesign of the task and the interface itself. We have previously argued that existing display design techniques that are simple and easily perceived would be the best choice for an interface that will be used in stressful environments (Hancock & Szalma, 2003a). Specifically, configural or object displays can represent complex, multivariable systems as simple geometric shapes or emergent features if those features are well-mapped to system dynamics (see Bennett & Flach, 1992). Under stress, the complex problem solving and analytical skills are the most vulnerable and decline first. A display that allows fast extraction of information with minimal cost in working memory load can mitigate stress effects (Hancock & Szalma, 2003a; Wickens, 1996). A combination of training to automaticity and displays of information that can be perceived directly with a minimum of information processing requirements is currently one of the best approaches for stress mitigation in cognitively complex environments.

Adaptive automation. Another approach for stress mitigation is the allocation of function to automated systems (Hancock & Chignell, 1987). The advent of modern automated systems allows for automation to adapt to the state of the individual (Scerbo et al., 2003). Thus, at points in time when an operator is overtaxed, the system can assume control of some task functions, thereby freeing resources to effectively cope with increased task demand. Two potential problems for automated systems are that over reliance can occur and operator skills can atrophy. However, a dynamic (adaptive) automated system that permitted or required the operator to perform functions at different points in time could reduce the probability of skill atrophy while still relieving the workload and stress of task performance.

However, the introduction of automation can itself induce stress. Operators who work with automated systems, particularly static, inflexible automation, are relegated to the role of monitors who must respond only when untoward events occur. Sustained

attention requirements are in fact quite stressful (Szalma, 1999; Warm, 1993), and paradoxically induce higher levels of perceived workload (Warm et al., 1996). Adaptive automation can mitigate this problem by dynamically assigning tasks to the machine or the human depending on the environmental conditions and the state of the operator (Hancock & Chignell, 1987). Indeed, efforts to use operator neurological state to adjust automation are currently underway (e.g., Scerbo, 2007).

Hedonomics: Promoting Enjoyable Human-Computer Interaction

Stress research has traditionally followed the edict of ergonomics and human factors in general, to do no harm and to prevent pain and injury. As with the rest of behavioral science, stress researchers sought to treat the symptoms of stress and mitigate its negative effects on performance. However, with the advent of positive psychology (Seligman & Csikszentmihalyi, 2000) there has been a movement to incorporate the promotion of pleasure and well-being rather than restricting efforts to pain prevention. Hancock coined the term *hedonomics* and defined it as that branch of science that facilitates the pleasant or enjoyable aspects of human-technology interaction (Hancock, Pepe, & Murphy, 2005). In short, the goal for hedonomics is to design for happiness. Hedonomics is a fairly new research area, but during the last 10 years, there has been a rapid growth in research concerning affect and pleasure. Affective evaluations provide a new and different perspective in Human Factors Engineering. It is not how to evaluate users—it is how the user evaluates (Hancock, Pepe, et al., 2005). The research on hedonic values and seductive interfaces is in fact a welcome contrast to safety and productivity, which have dominated human factors and ergonomics. Note, however, that pleasurable interaction with technology is not necessarily conducive to happiness. Indulging pleasures can sometimes interfere with happiness and well-being (see Fromm, 1976; Kasser, 2002; Ryan & Deci, 2001).

Our argument is not that we should discard current methods in human factors and ergonomics. Clearly functionality and usability are necessary conditions for pleasurable interaction with technology. If an interface does not function in a way congruent with the user's goals, so that the user appraises the technology as an agent that is interfering with goal achievement, that interaction is likely to be stressful and system performance more vulnerable to decline. However, function and usability are not sufficient conditions for pleasurable interactions with technology. The interface should be designed such that it affords appraisals of the technology as a convivial tool (Illich, 1973) or aid. One can also utilize the human tendency to anthropomorphize technology to facilitate appraisals of the technology as helpful and supportive rather than as an enemy (Luczak, Roetting, & Schmidt, 2003).

Hedonomic design will be of obvious importance for development of consumer products, but in principle, it can also transform the very nature of work, rendering it fun. Although there will be some tasks which will never be enjoyable, there are many individuals who have jobs that could be made more enjoyable by designing the tasks such that they promote teletic work (Csikszentmihalyi, 1990) and facilitate intrinsic motivation (Deci & Ryan, 2000).

Teletic work and intrinsic motivation. A useful theoretical framework for hedonomics is Self-Determination Theory (SDT; Deci & Ryan, 1985, 2000; Ryan & Deci, 2000, 2001). From this perspective there are three organismic needs that are essential for facilitating intrinsic motivation for task activity and the positive affect that can accompany such states. These needs are for competence (self-efficacy; see also Bandura, 1997), autonomy (personal agency, not independence per se), and relatedness. An important difference between this theory and other theories of motivation is the recognition that there are qualitatively different forms of motivation (Gagne & Deci, 2005). Thus, in SDT five categories of motivated behavior are identified that vary in the degree to which the motivation is self-determined. Four of the categories reflect extrinsic motivation and one category is intrinsic motivation. In the latter case, an individual is inherently motivated to engage in activity for its own sake or for the novelty and challenge. The four extrinsic motivation categories vary in the degree to which regulation of behavior is internalized by the individual and therefore more autonomous and self-determined (Ryan & Deci, 2000). The process of internalization involves transforming an external regulation or value into one that matches one's own values. The development of such autonomous motivation is crucial to skill development, since the person must maintain effort throughout a long and arduous process. Individuals who are autonomously motivated to learn are those who develop a variety of effective self-regulation strategies, have high self-efficacy, and who set a number of goals for themselves (Zimmerman, 2000). Further, effective self-regulation develops in four stages: observation, emulation, self-control, and self-regulation. Successful skill development involves focus on process goals in early stages of learning and outcome goals in the fourth stage (Zimmerman, 2000).

Intrinsic motivation and skill development. Research has established that intrinsic motivation is facilitated by conditions promoting autonomy, competence, and relatedness (see Deci & Ryan, 2000). Three factors that support autonomy are (a) meaningful rationale for doing the task, (b) acknowledgement that the task might not be interesting, and (c) an emphasis on choice rather than control. It is important to note that externally regulated motivation predicts poorer performance on heuristic tasks (Gagne & Deci, 2005), suggesting that as experts develop better knowledge representations it will be crucial to promote internal regulation of motivation. Although intrinsic motivation has been linked to how task activities and environmental contexts meet psychological needs, it is not clear why skilled performers are able to meet these needs, or why individuals choose a particular computer interface. It is likely that interest in activities codevelops with abilities and traits (see Ackerman & Heggestad, 1997), but this issue needs thorough investigation in the context of complex computer environments that require highly skilled workers.

In addition to the issue of efficacy and self-regulation, there is a need to examine the process by which individuals internalize extrinsic motivation as they gain experience with a particular interface or system. In particular, Gagne and Deci (2005) noted that little research has examined the effect of reward structures and work environments on the internalization process. It is likely that those environments that are structured to meet ba-

sic needs will more likely facilitate internalization processes and inoculate learners against the trials and tribulations that face them as they interact with new technologies.

Teletic work and motivational affordances. Teletic, or autoteletic, work refers to "work" that is experienced as enjoyable and is associated with flow or optimal experience characterized by a sense of well being and harmony with one's surroundings (Csikszentmihalyi, 1990). There is variation in both tasks and individuals with respect to the degree to which the human-technology interaction is teletic. There are four categories in which individuals tend to fall with respect to their relation to work. First, there is a small proportion of the population that are always happy in life, regardless of their activity, which Csikszentmihalyi referred to as individuals with an autotelic personality. There are also individuals who are predisposed to happiness about a specific task. They appraise such tasks as enjoyable, and seek out these activities. The third group consists of individuals who enjoy specific activities but cannot do them professionally, such as amateur athletes. The vast majority of people, however, do work for purely functional reasons (e.g., security). For these individuals work is boring and grinding because the task itself is aversive. A goal for hedonomics, then, is to design work that can be enjoyed to the greatest extent possible. This means structuring the environment as an entire system, ranging from the specific cognitive and psychomotor demands to the organization in which the person works. Even in jobs that are not inherently enjoyable, some degree of positive affect can be experienced by workers if they their environment is structured to facilitate a sense of autonomy (personal agency), competence, and relatedness (Deci & Ryan, 2000; see also Gagne & Deci, 2005). From an ecological perspective (e.g., Flach, Hancock, Caird, & Vicente, 1995), this means identifying the *motivational affordances* in the task and work environment, and designing for these affordances. Thus, just as one might analyze the affordance structure of an interface using ecological interface design methods (e.g., Vicente & Rasmussen, 1992), one can design an environment so that the elements of the physical and social environment afford stress reduction and enhanced intrinsic motivation. Note that although an affordance is a property of the environment, it does not exist independently of the individual in the environment. Affordances therefore share conceptual elements of person-environment transactions that drive emotion and stress. They differ in that the classical definition of an affordance is a physical property of the environment (Gibson, 1966, 1979), while a transaction emphasizes the individual's subjective appraisal of the environment. In both cases, however, one cannot define the concept by isolating either the individual or the context. Thus, although affordances and invariants are considered physical properties of the environment, these concepts are still relevant for motivational processes (and see Reed, 1996).

Motivational affordances may be conceived as elements of the work environment that facilitate and nurture intrinsic motivation. The key for design is to identify motivational invariants or environmental factors that consistently determine an individual's level of intrinsic motivation across contexts. There are some aspects of work that have been identified as important for facilitating intrinsic motivation and would thus be considered motivational invariants. For instance, providing feedback

that is perceived as controlling rather than informative tends to undermine a sense of autonomy and competence and thereby reduces intrinsic motivation (Deci, Ryan, & Koestner, 1999). Careful analyses of the motivational affordance structure will permit design of tasks that are more likely to be enjoyable by rendering the tools convivial (Illich, 1973) and thereby facilitating human-machine synergy (and see Hancock, 1997).

PROBLEMS FOR FUTURE RESEARCH

In this section, we will identify the areas for future research. These include a better understanding of resources and quantifying task dimensions defined in the Hancock and Warm (1989) model, which will likely reduce to the thorny problem of quantifying human information processing (see Hancock, Szalma, & Oron-Gilad, 2005). Further, we will discuss the need for research on performance-workload associations and dissociations, and the evident need for programmatic investigation of individual differences in performance, workload, and stress.

The Hancock and Warm (1989) model of stress explicitly identified task dimensions that influence stress state and behavioral adaptability. However, the metrics for these dimensions, and how specific task characteristics map to them, have yet to be fully understood. Thus, future research should aim to examine how different task components relate to performance and subjective and physiological state. Development of a quantitative model of task characteristics will permit the derivation of vectors for the prediction of adaptability under stress. Cognitive Neuroscience and Neuroergonomics in particular offer one promising approach to such development. An additional step in this direction, however, will be facilitated by improved quantitative models of how humans process information (Hancock, Szalma, & Oron-Gilad, 2005).

Understanding Mental Resources

One of the challenges for quantifying human information processing is that there is little understanding or consensus regarding the capacities that process the information. A central concept in energetic models of human performance is mental resources. Resource theory replaced arousal and served as an intervening variable to explain the relations between task demand and performance. However, a continual problem for the resource concept is to operationally define what it is. Most treatments of resources use that term metaphorically (Navon & Gopher, 1979; Wickens, 1980, 1984), and failures to specify what resources are have led some to challenge the utility of the concept (Navon, 1984). As resource theory is a central concept in the theories of stress discussed herein, and represents one of the most important issues to be resolved in future research on stress and performance, we now turn to the definitional concerns associated with the resource construct and the imperative for future research to refine the concept.

Resource metaphors. Two general categories of resource metaphors may be identified: structural metaphors and ener-

getic metaphors. One of the earliest conceptualizations of resource capacity used a computer-based metaphor (Moray, 1967). Thus, cognitive capacity was viewed as analogous to the RAM and processing chip of a computer, consisting of information processing units that can be deployed for task performance. However, the structural metaphor has been applied more to theories of working memory than to attention and resource theory.[1] Most early resource theories, including Kahneman's (1973) original view and modifications by Norman and Bobrow (1975), Navon and Gopher (1979), and Wickens (1980, 1984), applied energetic metaphors to resources, and conceptualized them as commodities or as pools of energy to be spent on task performance. In general, energetic approaches tend to employ either economic or thermodynamic/hydraulic metaphors. The economic model is reflected in the description of resources in terms of supply and demand: Performance on one or more tasks suffers when the resource demands of the tasks exceed available supply. Presumably, the total amount of this supply fluctuates with the state of the individual, with the assets diminishing with increases in the intensity or duration of stress. Although Kahneman's original conception allowed for dynamic variation available resource capacity, most early models assumed a fixed amount of resources (see Navon & Gopher, 1979). In thermodynamic analogies, resources are a fuel that is consumed, or a tank of liquid to be divided among several tasks, and under stressful conditions the amount of resources available is depleted and performance suffers. In discussing his version of resource theory, Wickens (1984) warned that the hydraulic metaphor should not be taken too literally, but most subsequent descriptions of resources have employed visual representations of resources as just this form (e.g., a tank of liquid). Similarly, many discussions of resource availability and expenditure adopt the economic language of supply and demand, and Navon and Gopher explicitly adopted principles of microeconomics in developing their approach. An additional problem for resource theory is that in most cases (e.g., Navon & Gopher, 1979; Wickens, 1980, 1984), the structural and energetic metaphors were treated as interchangeable, a further testament to the ambiguity of the construct.

A problem with using nonbiological metaphors to represent biological systems is that such models often fail to capture the complexity and the unique dynamic characteristics (e.g. adaptive responses) of living systems. For instance, a hydraulic model of resources links the activity of a tank of liquid, governed by thermodynamic principles, to the action of arousal mechanisms or energy reserves that are allocated for task performance. However, a thermodynamic description of the physiological processes underlying resources is at a level of explanation that may not adequately describe the psychological processes that govern performance. Thermodynamic principles can be applied to the chemical processes that occur within and between neurons, but they may be less useful in describing the behavior of large networks of neurons.[2] Similarly, economic metaphors of supply and demand may not adequately capture the relation between

cognitive architecture and energy allocated for their function. Economic models of resources define them as commodities to be spent on one or more activities, and they assume an isomorphism between human cognitive activity and economic activity, an assumption which may not be tenable. Indeed, Navon and Gopher (1979) admitted that their static economic metaphor for multiple resources may need to be replaced by a dynamic one that includes temporal factors (e.g. serial versus parallel processing; activity of one processing unit being contingent upon the output of another). Such concerns over the metaphors used to describe resources are hardly new (Navon, 1984; Wickens, 1984), but their use has become sufficiently ingrained in thinking about resources and human performance that reevaluation of the metaphors is warranted. A regulatory model based on physiology may serve as a better metaphor (and, in the future may serve to describe resources themselves to the extent that they can be established as a hypothetical construct) to describe the role of resources in human cognition and performance. However, even a physiologically-based theory of resources must be tempered by the problems inherent in reducing psychological processes to physiological activity.

Function of resources. Another problem for resource theory is the absence of a precise description of how resources control different forms of information processing. Do resources determine the energy allocated to an information processor (Kahneman, 1973), do they provide the space within which the processing structure works (Moray, 1967), or does the processor draw on the resources as needed (and available)? In the latter case, the cognitive architecture would drive energy consumption and allocation, but the locus of control for the division of resources remains unspecified in any case. Presumably, an executive function that either coordinates information processors drawing on different pools of resources or decides how resources will be allocated must itself consume resources, in terms of both energy required for decision making and mental space or structure required. Hence, resource theory does not solve the homunculus problem for theories of attention, nor does it adequately describe resource allocation strategies behind performance of information processing tasks.

Empirical tests of the model. Navon and Gopher (1979) commented on the problem of empirically distinguishing declines in performance due to insufficient supply from those resulting from increases in demand. They asked, "When the performance of a task deteriorates, is it because the task now gets fewer resources or because it now requires more?" (p. 243). Navon and Gopher characterized the problem as distinguishing between changes in resources and changes in the subject-task parameters that constrain resource utilization, and they offered two approaches to avoid this difficulty. One approach is to define the fixed constraints of the task and observe how the information processing system manages the processes within those constraints. The degree of freedom of the system, in this view,

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[1]This is a curious historical development, since these relatively separate areas of research converge on the same psychological processes.

[2]The argument here is not that neural structures are not constrained by the laws of thermodynamics—clearly they are—but that thermodynamic principles implied by the metaphor are not sufficient for the development of a complete description of resources and their relation to cognitive activity.

is the pool of resources available, in which the term *resource* is interpreted broadly to include quality of information, number of extracted features, or visual resolution. The subject-task parameters define what is imposed on the system (the demands) and the resources refer to what the system does in response to the demands (allocation of processing units). From this perspective resources can be manipulated by the information processing system within the constraints set by the subject-task parameters. A second approach is to distinguish the kind of control the system exerts on resources, between control on the use of processing devices (what we have called "structure") and the control of the properties of the inputs that go into these devices. The devices are processing resources. The other kind of control is exerted on input resources, which represents the flexibility the person has for determining which inputs are operated on, as determined by subject-task parameters. Processing resources are limited by the capacities of the information processors, while the input resources are limited by subject-task parameters (and allocation strategies that determine which information the operator attends to). Presumably, the individual would have some control over the allocation strategy, in terms of the processing resources devoted to a task, although these can also be driven by task demands (e.g. a spatial task requires spatial processing units). Navon and Gopher did not advocate either approach, but presented them as alternatives for further investigation. The implication for examining the resource model of stress is that one must manipulate both the subject-task parameters (e.g. by varying the psychophysical properties of the stimulus, manipulating the state of the observer, or varying the kind of information processing demanded by the task) as well as the allocation strategies the operator uses (the input resources— e.g. payoff matrices, task instructions). This would provide information regarding how specific stressors impair specific information processing units and how they change the user's resource allocation strategies in the presence of stress that is continuously imposed on operators of complex computer-based systems.

In a later article, Navon (1984) moved to a position less favorable toward resources than the earlier approach, asserting that predictions derived by resource theory could be made, and results explained, without appealing to the resource concept (see also Rugg, 1986). One could instead interpret effects in terms of the outputs of information processors. Most manipulations, such as difficulty (which in his view influences the efficiency of a unit of resources) or complexity (which affects the load, or the number of operations required) influence the demand for processing, with supply having no impact upon their interaction. However, this approach assumes a clear distinction between outputs of a processing system and the concept of a resource, and Navon's notion of specific processors seems blurred with the notion of a resource, as both are utilized for task performance. Nevertheless, his critique that the regarding the vagueness of the resource concept is relevant, and Navon argued that if resources are viewed as an intervening variable rather than a hypothetical construct, the concept has utility for describing the process.

Structural mechanisms. If different kinds of information processing draw on different kinds of resources, in terms of the

information processors engaged in a task, stressors may have characteristic effects on each resource. In addition, as Navon and Gopher (1979) noted, an aspect of resource utilization is the efficiency of each resource unit. It may be that stress degrades the efficiency of information processing units, independent of energy level or allocation strategy (cf., Eysenck, M. W. & Calvo, 1992). Investigation of such effects could be accomplished by transitioning between tasks requiring different kinds of information processing and determining if the effects of stress on one structure impacts the efficiency of a second structure.

The quality of resources can vary not only in terms of the kind of information processing unit engaged, but also in terms of the kind of task required. Following Rasmussen's (1983) classification system for behavior as a heuristic for design, some tasks require knowledge-based processing, in which the operator must consciously rely on his or her mental model of the system in order to achieve successful performance. Other tasks fall under the category of rule-based behavior, in which a set rules or procedures define task performance. The third category is skill-based behavior, in which the task is performed with a high degree of automaticity. Presumably, each kind of task requires different amounts of resources, but they may also represent qualitatively different forms of resource utilization. In other words, these tasks may differ in the efficiency of a unit of resources as well as different effort allocation strategies. As task performance moves from knowledge to rule to skill based processing (e.g. with training), the cognitive architecture may change such that fewer information processing units are required, and those that are engaged become more efficient. Moreover, the way in which each of these systems degrade with time under stress may be systematic, with the more fragile knowledge-based processing degrading first, followed by rule based processing, with skill based processing degrading last (at this point, one may begin to see breakdown of not only psychological processes but physiological ones as well; see Hancock & Warm, 1989). This degradation may follow a hysteresis function, such that a precipitous decline in performance occurs as the operator's resource capacity is reduced below a minimum threshold for performance. Moreover, these processes may recover in an inverse form, with skill-based processing recovering first, followed by rule and knowledge-based processing.

Note that it may be difficult to distinguish pure knowledge-based processing from rule- or skill-based activity. An alternative formulation is the distinction between controlled and automatic processing (Schneider & Shiffrin, 1977). Although originally conceived as categories, it is likely that individuals engaged in real-world tasks utilize both automatic and controlled processing for different aspects of performance and that for a given task there are levels of automaticity possible. Treating skills as a continuum rather than as discrete categories may be a more theoretically useful framework for quantifying resources and information processing, and thereby elucidating the effects of stress on performance.

Energetic mechanisms. To investigate the energetic aspects of resources, one must manipulate environmentally-based perturbations, in the form of external stressors (noise, heat) and task demands, to systematically affect inflow versus

outflow of energy. Presumably, inflow is controlled by arousal levels, physiological energy reserves, and effort. One could examine performance under manipulations of energetic resources under dual task performance (e.g., What happens to performance on two tasks under sleep deprivation or caffeine consumption?). For example, the steady state can be perturbed by increasing (e.g. caffeine) or decreasing (e.g. sleep deprivation) energy while systematically varying the demands for two tasks.

Structure and energy. Another empirical challenge is to distinguish resources as structure from resources as energy. Given the definitional problems associated with the resource concept, it is not clear whether performance declines because of reduction in energy level or degradation in structures (e.g., failures or declines in the efficiency of the processing units), or a combination of both. If structure and energy are distinct elements of resources, it is hypothetically possible to manipulate one while holding the other constant, although the validity of that assumption is questionable. Is it possible to manipulate specific forms of information processing under constant energy level? Is it possible to manipulate energy level independent of which cognitive processes are utilized? If the decline in available resources is, at least in part, due to the degradation of particular information processing units, then transferring to a task requiring the same processor should lead to worse performance than transferring to one that is different (cf., Wickens, 1980, 1984). For instance, if a person engages in a task requiring verbal working memory while under stress, then transitions to a task requiring spatial discrimination, performance on the latter should depend only on energetic factors, not on structural ones. Note, however, that in this case the effects of different mental capacities would be confounded with the effects of novelty and motivation on performance.

Application of neuroergonomics. The burgeoning field of Neuroergonomics seeks to identify the neural bases of psychological processes involved in real-world human-technology interaction (Parasuraman, 2003). As we have stated elsewhere (Hancock & Szalma, 2007), recent advances in Neuroergonimcs promises to identify cognitive processes and their link to neurological processes. This may permit a more robust and quantitative definition of resources, although we caution that a reductionistic approach is not likely to be fruitful (and see Hancock & Szalma, 2003b). In addition, the stress concept itself rests in part on more precise definitions of resources (Hancock & Szalma, 2007). Thus, resolution of the resource issue in regard to cognitive processing and task performance would also clarify the workload and stress concepts. We view Neuroergonomics as one promising avenue for future research to refine the workload and stress and resource concepts.

Development of the Adaptation under Stress Model

Quantify the task dimensions. A major challenge for the Hancock and Warm (1989) model is the quantification of the base axes representing task dimensions. Specification of these dimensions is necessary if the vector representation postulated

by Hancock and Warm is to be developed and if the resource construct is to be more precisely defined and quantified. However, task taxonomies that are general across domains present a theoretical challenge, because they require an understanding and quantification of how individuals process information along the spatial and temporal task dimensions, and how these change under stressful conditions. Quantification of information processing, and subsequent quantification of the base axes in the Hancock and Warm model, permit the formalization of the vector representation of adaptive state under stress (see Fig. 6.4).

Attentional narrowing. Recall that Hancock and Weaver (2005) argued that the distortions of spatial and temporal perception have a common attentional mechanism. Two implications of this assertion are (a) that events (internal or external) that distort one dimension will distort the other, and (b) that these distortions are unlikely to be orthogonal. With very few exceptions, little research has addressed the possibility of an interaction between distortions of spatial and temporal perceptions in stressful situations on operator performance. Preliminary evidence suggests that these two dimensions may in fact not share a common mechanism (Ross et al., 2003; Thropp et al., 2004), although further research is needed to confirm these findings. An additional important issue for empirical research is whether we are dealing with time-in-memory or time-in-passing (and to some extent space-in-memory vs. space-in-passing). Thus, the way in which perceptions of space and time interact to influence operator state will depend upon how temporal perceptions (and spatial perception, for that matter) are measured.

A possible explanation for perceptual distortions under conditions of heavy workload and stress concerns the failure to switch tasks when appropriate. Switching failures may be responsible for the observation in secondary task methodology that some participants have difficulty dividing their time between tasks as instructed (e.g., 70% to the primary task and 30% to the secondary task). This difficulty may result from the participant's inability to accurately judge how long he or she has attended to each task during a given time period. The degree to which distortions in perception of space-time are related to impairments in task switching under stressful conditions, and the degree to which these distortions are related to attention allocation strategies in a secondary task paradigm, are questions for empirical resolution.

Stressor characteristics. Even if space and time do possess a common mechanism, it may be that specific stressors do not affect spatial and temporal perceptions in the same way. For instance, heat and noise may distort perception of both space and time, but not to the same degree or in the same fashion. It is important to note that spatial and temporal distortions may be appraised as stressful, as they might interfere with the information processing requirements of a task. Consequently, some kinds of information processing might be more vulnerable to one or the other kind of perceptual distortion. Clearly, performance on tasks requiring spatial abilities, such as mental rotation, could suffer as a result of spatial distortion, but they might be unaffected (or, in some cases, facilitated) by temporal distortion. Other tasks, such as those that rely heavily on working memory, mathematical ability, or tasks requiring target detec-

tion, could each show different patterns of change in response to space-time distortion.

Potential benefits of space-time distortion. Under certain conditions, the narrowing of spatial attention can benefit performance through the elimination of irrelevant cues. The precise conditions under which this occurs, however, remains unclear. In addition, it is important to identify the circumstances under which time distortion might actually prove beneficial. Here, operators perceive that they have additional time to complete the task at hand (Hancock & Weaver, 2005). This would have great benefit in task performance situations where attentional narrowing is less likely to have deleterious effects. At this point, this is an empirical question that might be amenable to controlled testing.

Changes in adaptation: the roles of time and intensity. The degree to which a task or the physical and social environment imposes stress is moderated by the characteristics of the stimuli as well as the context in which events occur. However, two factors that seem to ubiquitously influence how much stress impairs adaptation are the (appraised) intensity of the stressor and the duration of exposure. We have recently reported meta-analytic evidence that these two factors jointly impact task performance across different orders of task (e.g., vigilance, problem solving, tracking; see Hancock, Ross, & Szalma, in press). Duration is further implicated in information processing itself, and may be a central organizing principle for information processing in the brain (Hancock, Szalma, & Oron-Gilad, 2005). Empirical research is needed, however, to programmatically explore the interactive effects of these two variables across multiple forms of information processing.

Understanding Performance-Workload Associations/Dissociations

Task factors. Although Hancock (1996) and Yeh and Wickens (1988) articulated the patterns of performance-workload relations and how these are diagnostic with respect to processing requirements, there has been little systematic effort to further investigate these associations/dissociations. The primary question is what factors drive dissociations and insensitivities when they occur. For instance, for vigilance mostly associations are observed, while for other tasks, such as those with high working memory demand, dissociations are more common (Yeh & Wickens, 1988). Enhanced understanding of these relations would inform the Hancock and Warm (1989) model by permitting specification of the conditions under which individuals pass over the thresholds of failure at each level of person-environment transaction/adaptation.

Multidimensionality of workload. To date, consideration of performance-workload dissociations has been primarily concerned with global measures of perceived workload. However, there is clear evidence that perceived workload is in fact multidimensional. For instance, vigilance tasks are characterized by high levels of mental demand and frustration (Warm, Dember, & Hancock, 1996). It is likely that the pattern of performance-

workload links will be different for different orders of performance (different tasks) but also for different dimensions of workload. One approach to addressing this question would be to systematically manipulate combinations of these two variables. For instance, if we consider performance in terms of detection sensitivity, memory accuracy, speed of response, and consider the dimensions of workload defined by the NASA Task Load Index (Hart & Staveland, 1988), one could examine how variations in memory load or discrimination difficulty link to each subscale.

INDIVIDUAL DIFFERENCES IN PERFORMANCE, WORKLOAD, AND STRESS

Elsewhere, we reviewed the relations between individual differences in state and trait to efforts to quantify human information processing (Szalma & Hancock, 2005). Here, we address how individual differences (state and trait) are related to stress and coping.

Trait Differences

Individual differences research has been a relatively neglected area in human factors and experimental psychology. Much of the early work on individual differences was done by individuals not concerned with human-technology interaction, to the extent that a bifurcation between two kinds of psychology occurred (Cronbach, 1957). There is evidence, however, that affective traits influence information processing and performance. Thus, extraversion is associated with superior performance in working memory tasks and divided attention, but also with poorer sustained attention (cf., Koelega, 1992). Trait anxiety is associated with poorer performance, although results vary across task types and contexts (Matthews et al., 2003). A possible next step for such research will be to systematically vary task elements, as discussed previously in the context of the Hancock and Warm (1989) model, and test hypotheses regarding how trait anxiety relates to specific task components (for an example applied to Extraversion, see Matthews, 1992). The theoretical challenge for such an undertaking is that it requires a good taxonomic scheme for tasks as well as a well-articulated theory of traits and performance. However, trait theories have neglected specific task performance, focusing instead on global measures (e.g., see Barrick, Mount, & Judge, 2001), and there is a lack of a comprehensive theory to account for trait-performance relations (Matthews et al., 2003). Most current theories are more like frameworks that do not provide specific mechanisms for how personality impacts cognition and performance (e.g., see McCrae & Costa, 1999). Although H. J. Eysenck (1967) proposed a theory of personality based on arousal and activation, which has found some support (Eysenck & Eysenck, 1985), there has also been evidence that arousal and task difficulty fail to interact as predicted (Matthews, 1992). H. J. Eysenck's (1967) theory was also weakened by the general problems associated with arousal theory accounts for stress effects (Hockey, R., 1984). An alternative formulation is that of Gray (1991), who argued for two systems, one responding to reward signals and one with

punishment. The behavioral activation system (BAS) is associated with positive affect, while the behavioral inhibition system with negative affect. In a review and comparisons of the H. J. Eysenck and Gray theories, Matthews and Gilliland (1999) concluded that both theories have only been partially supported, but that Gray's BAS/BIS distinction provides a superior match to positive and negative affect relative to H. J. Eysenck's arousal dimensions. Further, the BAS/BIS accords with theories of approach/avoidance motivation (e.g., Elliot & Covington, 2001). There are also theories that focus on a particular trait, such as Extraversion (Humphreys & Revelle, 1984) or trait anxiety (Eysenck, M. W., & Calvo, 1992). While useful, such specific theories do not encompass other traits or interactions among traits. Such interactive effects can influence cognitive performance and perceived stress and workload (Szalma, Oron-Gilad, Stafford, & Hancock, 2005). These interactions should be further studied with an eye to linking them to information processing theories.

Affective State Differences

It is intuitive that stress would induce more negative affective states, and that traits would influence performance via an ef-

fect on states. For instance, one would expect that trait anxiety would influence performance because high trait anxious individuals experience state anxiety more frequently than those low on that trait. While such mediation effects are observed, there is also evidence that, for certain processes, such as hyper vigilance to threat, trait anxiety is a better predictor of performance than state anxiety (Eysenck, M. W., 1992). In terms of appraisal theory, traits may influence the form and content of appraisal, as well as the coping skills the individual can deploy to deal with the stress. In regard to the adaptation, it is likely that individual differences in both trait and state will influence adaptation, both behavioral and physiological, by affecting the width of the plateau of effective adaptation at a given level, and by changing the slope of decline in adaptation when the adaptation threshold has been reached. That is, higher skill levels protect from declines in adaptive function by increasing the threshold for failure at a given level (e.g., comfort, performance, physiological response). The modification of the Hancock and Warm (1989) model, illustrating these individual differences effects, is shown in Fig. 6.6. Multiple frameworks of state dimensions exist, but most focus on either two (e.g., Thayer, 1989; Watson & Tellegen, 1985), or three (Matthews et al., 1999, 2002). In the context of task performance, Matthews and his colleagues identified three
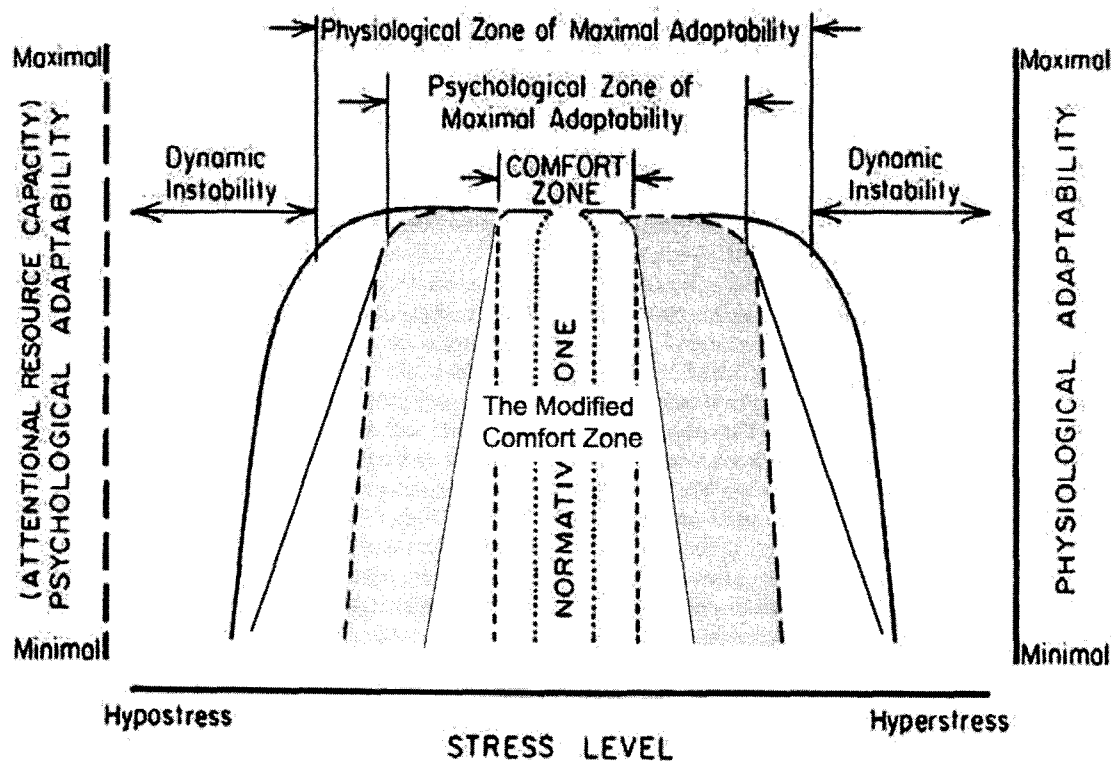

FIGURE 6.6. The adaptability model of Hancock and Warm (1989) shown in Figure 3 has been modified to illustrate how individual differences may influence stress and adaptation. It is likely that cognitive and affective traits influence both the width of the comfort and performance zones (i.e., the 'thresholds' for declines in adaptation) as well as the rate of decline in adaptability when a threshold has been crossed. For instance, individuals high in trait anxiety would likely have a narrower plateau of stability and would therefore manifest lower thresholds for discomfort and performance degradation than individuals low on that trait. Further, the rate of decline in adaptation may increase as a function of trait anxiety.

broad state dimensions reflecting the cognitive, affective, and motivational aspects of an individual's current psychological state. These dimensions are "worry," which reflects the cognitive dimension of stress, and "task engagement" and "distress," which reflect the affective, cognitive, and motivational components of state. Specifically, a high level of distress is indicative of overload in processing capacity, while task engagement reflects a theme of commitment to effort (Matthews et al., 2002). Matthews and his colleagues (2002) demonstrated that changes in task demand influence the pattern of stress state. It is therefore important to incorporate assessment of operator state into the interface design process so that the interaction with the technology fosters task engagement and minimizes distress and worry.

Attentional narrowing and adaptive response. As with other aspects of perception, there are individual differences in the perception of space and time (Hancock & Weaver, 2002; Wachtel, 1967). Further, because the subjective experience of stress is often multidimensional, it may be that two individuals are subjectively stressed by the same situation but that their stress state profiles differ. Individuals are also likely to differ in the strategies they employ to cope with the distortions of space-time they experience while in a stressful environment, and these coping differences, if they exist, might depend on the quality (e.g. noise, heat, low signal salience) and source (e.g. environment, the task) of the stress and the personality traits of the individual.

Hedonomics and individual differences. In addition to application of individual differences research to development of training or selection procedures, individual of relevant individual different variables can promote hedonomic approaches to design and facilitate individuation in interface design. Thus, if the traits that influence the subjective experience of an interaction with technology are identified, that interface can then be configured to meet the preferences and the trait/state profile of the individual user and promote positive affective states. However, for such efforts to succeed, the relations among traits and cognitive, perceptual, and motor performance will need to be established via theory-guided empirical research.

IMPLICATIONS OF STRESS FOR RESEARCHERS AND PRACTITIONERS

For both research and design application, the extant research on stress and performance indicates that assessment of workload and affective state are important for a more complete understanding of HCI. Such assessments can aid in identifying which components of an interface or task are appraised as stressful and thereby design to mitigate their negative effects. For instance, research is needed to establish which task parameters control the patterns of performance-workload associations and dissociations, and how these change dynamically as a function of time on task. The Hancock and Warm (1989) model of stress established general task dimensions (space-time) that influence stress state and behavioral adaptability, but the metrics

for these dimensions remain elusive. This problem results from the central issue regarding how to quantify human information processing (Hancock, Szalma, & Oron-Gilad, 2005) and define mental resources more precisely (Hancock & Szalma, 2007). Efforts to resolve these definitional problems would improve stress theory and its application to interface design. Future research should therefore examine the relations between task dimensions and user characteristics, and how these change over time and under high-stress conditions.

In addition to changing the task, there are other techniques that can be applied to the design of HCIs for use in stressful environments. These include skill development (e.g., Hancock, 1986) and use of configural displays (Hancock & Szalma, 2003a; Wickens, 1996), as well as technologies employing adaptive automation and decision aids (Hancock & Chignell, 1987). In regard to skill development in particular, an area in need of research is how individuals who develop expertise also learn how to cope with stress while performing the task. Understanding how individuals accomplish this will require advances in understanding how different forms of stress influence different forms of information processing.

It is also important for both researchers and practitioners to consider the characteristics of the user and to consider how these characteristics interact with the task or interface to influence performance. Understanding how individual differences influence human-computer interaction can facilitate development of tailored training regimens as well as interfaces that more effectively adapt to the user. Systems that can respond to changes in operator affective state will achieve the desired human-machine synergy in HCI (c.f., Hancock, 1997). Realizing these goals, however, will require adequate theory development and subsequent empirical research to determine the nature of the relations among the person and environmental variables. It will be particularly important to design interfaces that permit autonomous motivation (Deci & Ryan, 2000), and to understand how operators of computer-based systems can internalize extrinsic motivation as they gain experience with the task. (Gagne & Deci, 2005). We suggest here that researchers and designers identify the motivational affordances in the task environment and utilize these to enhance the experience of HCI and improve overall system performance under stress. Motivational affordances will be elements of the work environment that facilitate and nurture intrinsic motivation. Particularly important for design will be to identify motivational invariants, which are those environmental factors that consistently determine an individual's level of intrinsic (or extrinsic) motivation across contexts. Careful analyses of the motivational affordance structure will permit design of tasks that are more likely to be enjoyable by rendering the tools convivial (Illich, 1973) and thereby facilitating human-machine synergy (and see Hancock, 1997).

SUMMARY AND CONCLUSIONS

In this chapter, we reviewed three theories of stress and performance and their relevance for human-technology interaction. We also showed that despite separate research traditions, work-

load and stress might be viewed as different perspectives on the same problem. We outlined some general principles for stress mitigation, and issues requiring further research. Of particular importance will be establishing sound measures of information processing and mental resources, as well as articulating the relevant task dimensions and how they relate to self-regulatory mechanisms. Given that stress can only be understood in relation to the transaction between an individual and the environment, it will be crucial to establish how traits and states of the individual influence their appraisals of their environments. Finally, it will be important in practical application to treat stress at multiple levels, ranging from the physiological to the organizational sources of adverse performance effects. Traditional attempts to treat stress problems unidimensionally will continue to fail until the person, task, and physical, social, and organizational environments are treated as a system. Researchers and practitioners in HCI should therefore expand their efforts beyond the design of the displays and controls of interfaces and include assessment of the person factors that influence performance as well as the design of the physical and social environment in which the human-computer interaction occurs.

The argument here is not that neural structures are not constrained by the laws of thermodynamics—clearly they are—but that thermodynamic principles implied by the metaphor are not sufficient for the development of a complete description of resources and their relation to cognitive activity.

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