THE MODERATING INFLUENCE OF STRESS APPRAISALS AND AFFECT ON PERFORMANCE UNDER FATIGUE

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ABSTRACT

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This study demonstrated that in a group of seventeen active duty soldiers, performance on an attack combat simulation significantly degraded after approximately 30 h of sleep deprivation. In addition, individual differences were identified, as approximately half of the participants maintained performance throughout the sleep deprivation period, while other participants degraded in performance. The main objective of this study was to test the efficacy of micro-level cognitive performance and subject state factors to account for this dichotomy in performance that was particular to the last testing session. Results showed that performance on a decision making test with rapid reaction time constraints was predictive of performance changes on the attack combat scenario. It was also found that individuals who were able to sustain performance made secondary task errors after 18 hours of continued wakefulness, suggesting a strategic change of task shedding, followed by a heightened sense of secondary task awareness. This study also demonstrated that stress appraisals did not significantly change under continued wakefulness, nor did stress appraisals explain performance differences. It was also found that individuals who were capable of maintaining performance exhibited an increase in levels of anxiety over the continued wakefulness period. This finding can be explained in the context of the inverted-U hypothesis, which states that performance inhibiting stressors such as continued wakefulness will lead to less arousal and poorer performance while performance facilitation will occur under additional stressors that
increase arousal, such as anxiety. It is concluded that the ability to manage increases in task demands involves making adjustments to subject state variables. Further studies should investigate personality factors that predict this ability. The present study suggests that self-regulation properties are operating for individuals who are able to sustain performance under fatigue.
TABLE OF CONTENTS

LIST OF TABLES .............................................................................................................. vii

LIST OF FIGURES .......................................................................................................... viii

I. INTRODUCTION ..................................................................................................... 1

II. BACKGROUND ........................................................................................................ 7

  Fatigue ...................................................................................................................... 7
  The Effects of Continued Wakefulness on Cognitive Performance .................................. 7
  Individual Differences in Fatigue Vulnerability ............................................................ 11

  Affect, Stress Appraisals, and Performance .................................................................. 12

  Fatigue, Stress Appraisals, Affect, and Performance ..................................................... 18

  Summary of Research Questions .................................................................................. 20

III. METHOD ............................................................................................................... 23

  Participants .............................................................................................................. 23

  Instruments and Apparatus ....................................................................................... 24

    Psychological Measures .......................................................................................... 24

    Cognitive Measures ............................................................................................... 25

    Test Facility and Stimuli ......................................................................................... 26

  Procedures ............................................................................................................... 29

IV. DATA ANALYSIS .................................................................................................. 33

  Modeling of Variables ............................................................................................... 35

  Flashpoint Attack Combat Simulation .......................................................................... 36

  ACRA-Rapid Decision Making .................................................................................. 41

  ACRA-Tower of Hanoi .............................................................................................. 48

  Participant State Variables ....................................................................................... 52

    Stress Appraisals .................................................................................................... 53

    Affect ....................................................................................................................... 57

  Explaining Fatigue Vulnerability for the Rapid Decision Making Test ....................... 60

  Explaining Fatigue Vulnerability using Classification based on Multiple Criteria ........ 64

    Stress Appraisals .................................................................................................... 65

    Affect ....................................................................................................................... 65

  Summary ................................................................................................................. 68

V. DISCUSSION ........................................................................................................... 70

  Synthetic Task Performance ....................................................................................... 70

  Stress Appraisals ....................................................................................................... 72

  Affect ......................................................................................................................... 73

  Can we Identify Fatigue Vulnerability? ....................................................................... 76

  Study Limitations ...................................................................................................... 78
Reference List ...........................................................................................................81
APPENDIX A ...........................................................................................................89
APPENDIX B ...........................................................................................................97
APPENDIX C ...........................................................................................................98
APPENDIX D ...........................................................................................................99
APPENDIX E .........................................................................................................105
APPENDIX F .........................................................................................................106
LIST OF TABLES

Table 1. Means and standard deviations for study variables .................................................. 34

Table 2. Rapid Decision Making classification as a function of differences in performance from
session 1 to session 6 .................................................................................................................. 43

Table 3. Enemy kills and Rapid Decision Making percent correct group categorization ............ 44

Table 4. Enemy kills and Rapid Decision Making reaction time variability group categorization .......................................................... 44

Table 5. Enemy kills and Rapid Decision number of misses group categorization .................. 45

Table 6. Stable vs. fatigue vulnerable classification comparisons between the number of enemy kills
and the Tower of Hanoi performance metrics ........................................................................... 50

Table 7. Anxiety change scores as a function of fatigue for both the stable and fatigue vulnerable
groups .......................................................................................................................................... 60

Table 8. Proportions of changes in anxiety for both the cross-stable and cross-fatigue vulnerable
groups ........................................................................................................................................... 67
LIST OF FIGURES

Figure 1. Closed-Loop Model of Strategic Control (Wickens and Holland, 2000) ......................... 14

Figure 2. Adaptation of Wickens and Holland’s (2000) model of strategic control under stress ...... 17

Figure 3. A representation of the effect of fatigue on performance ........................................... 20

Figure 4. Example snapshot of 2-D configuration ................................................................. 27

Figure 5. Participant “Aim” and “Fire” presentation during Operation Flashpoint ......................... 28

Figure 6. Forty-eight hour test schedule ............................................................................... 31

Figure 7. The number of enemy kills over continued wakefulness sessions ................................. 37

Figure 8. Individual differences in enemy kills trends over continued wakefulness sessions ......... 37

Figure 9. Change in the number of enemy kills from session 1 to session 6 by group .................. 38

Figure 10. The number of enemy kills over continued wakefulness sessions: stable vs. fatigue vulnerable groups .......................................................... 39

Figure 11 (a) & (b). Number of mine kills and casualties: stable vs. fatigue vulnerable groups ....... 40

Figure 12. Rapid Decision Making percent correct as a function of continued wakefulness ..... 42

Figure 13. Rapid Decision Making reaction time variability as a function of continued wakefulness 42

Figure 14. Rapid Decision Making performance as a function of continued wakefulness .......... 42

Figure 15. Rapid Decision Making Percent Correct as a function of continued wakefulness: stable vs. fatigue vulnerable groups as categorized by the combat simulation ........................................ 46

Figure 16. Rapid Decision Making reaction time variability as a function of continued wakefulness: stable vs. fatigue vulnerable groups .......................................................... 46

Figure 17. Rapid Decision Making number of misses as a function of continued wakefulness: stable vs. fatigue vulnerable groups .......................................................... 47

Figure 18. Tower of Hanoi time to completion as a function of continued wakefulness ........... 48

Figure 19. Tower of Hanoi number of moves as a function of continued wakefulness ............. 48

Figure 20. Tower of Hanoi number of legality errors as a function of continued wakefulness ..... 49

Figure 21. Tower of Hanoi number of moves as classified by the combat simulation: stable vs. fatigue vulnerable groups .......................................................... 51

Figure 22. Tower of Hanoi solution time as classified by the combat simulation: stable vs. fatigue vulnerable groups .......................................................... 52

Figure 23. Tower of Hanoi number of legality errors as classified by the combat simulation: stable vs. fatigue vulnerable groups .......................................................... 52
Figure 24. Stress appraisal ratios as classified by the combat simulation: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 56

Figure 25. Positive affect as classified by the combat simulation: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 57

Figure 26. Negative affect as categorized by the combat simulation: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 58

Figure 27. Anxiety as classified by the combat simulation: stable vs. fatigue vulnerable groups………………… 59

Figure 28. Positive affect as classified by the Rapid Decision Making percent correct metric: stable vs. fatigue vulnerable groups…………………………………………………………………………………………………… 61

Figure 29. Positive affect as classified by the Rapid Decision Making reaction time variability metric: stable vs. fatigue vulnerable groups…………………………………………………………………………………………………… 62

Figure 30. Positive affect as classified by the Rapid Decision Making number of misses metric: stable vs. fatigue vulnerable groups…………………………………………………………………………………………………… 62

Figure 31. Negative affect as classified by Rapid Decision Making reaction time variability: stable vs. fatigue vulnerable groups…………………………………………………………………………………………………… 63

Figure 32. Depression as categorized by Rapid Decision Making misses: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 64

Figure 33 (a) & (b). Stress appraisals prior to both the combat simulation and the Rapid Decision Making test: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 65

Figure 34 (a) & (b). Negative affect scores prior to both the combat simulation and the Rapid Decision Making test: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 66

Figure 35 (a) & (b). Anxiety scores prior to both the combat simulation and the Rapid Decision Making test: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 67

Figure 36 (a) & (b). Depression scores prior to both the combat simulation and the Rapid Decision Making test: stable vs. fatigue vulnerable groups……………………………………………………………………………………………………………… 68

Figure 37. Supported links in the Arousal-Fatigue Model……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………
I. INTRODUCTION

“…At the heart of the Objective Force are Soldiers and leaders – Warriors – who will go into harm’s way to impose our nation’s will on any adversary. They must know and live Army values, be disciplined, be physically tough and mentally conditioned for combat, have perseverance, be competent in our doctrine, and possess the will to win – these are the precepts of physical and psychological force domination…”

*Eric Shinseki, United States Army General.*

The U.S. Army warfighter is one of the most resilient entities in the area of human performance. The warfighter must be ready physically, cognitively, and affectively to face the most challenging circumstances in a manner that will dominate powerful adversaries. Though years of research in the laboratory and field have identified situational elements that can lead to the deterioration of an active unit, these warfighters continue to face adversity with continued perseverance. The warfighter encounters sustained operations that can last up to 72 hours without rest, leaving our soldiers vulnerable to the effects of sleep deprivation.

Fatigue in the workplace is an ongoing problem affecting performance quality and human safety in multiple domains. A few examples are listed below, which are actual fatigue-related incidents.

*Trucking Industry.* According to the National Transportation Safety Board (2004), On June 23, 2002, a 55-passenger Motor Coach Industries, Inc. motorcoach was traveling eastbound on Interstate 90 near Victor, New York. As it approached the
Victor Exit 45 ramp, the bus departed the road; struck a W-beam guardrail dragging about 700 feet of it across the eastbound entrance ramp; vaulted over the entrance ramp, landing on the ramp’s south side shoulder; and rolled 90 degrees onto its right side, sliding to rest. The guardrail dragged by the bus during the accident sequence struck three eastbound vehicles on the entrance ramp. Three occupants of these vehicles were uninjured, and six received minor injuries. Of the 48 people on the motorcoach, 5 passengers were killed; the driver and 41 passengers sustained injuries; and 1 passenger was uninjured. Several factors indicate that the driver fell asleep while operating the motorcoach before it left the roadway. The driver had obtained no nighttime sleep and only three brief naps totaling less than 4 hours in the 51 hours preceding the accident.

*Air Traffic Control.* On October 23, 2001, the National Transportation Safety Board concluded that mistakes by a fatigued cockpit crew caused the 1999 crash of an American Airlines jetliner in Little Rock Ark, killing 11 and injuring 105 passengers. Studies by NASA and the Battelle Memorial Institute have concurred with pilot unions that a pilot should not be on duty more than 12 hours. Incidentally, by the time the ill-fated plane neared Little Rock, the crew had been on duty for about 13 1/2 hours (Malnic, 2001).

*Anesthesiology.* A fatal case report of an anesthesiologist who fell asleep whilst anaesthetising an eight-year-old made front page in the *Denver Post.* During testimony it was claimed that the defendant had been
repeatedly warned about falling asleep during operations. He was convicted of criminal medical negligence (Prankratz, 2004).

The above examples demonstrate the fatal consequences of fatigued operators. In the commercial environment such as public airline transportation and medical practice, fatigue management strategies, such as limiting the amount of flight hours for pilots or instituting napping regulations, are less difficult to implement than in military operations. The operational environment inherently demands sustained operations, thus it is critical to be able to identify individuals who can sustain performance under circumstances with the potential for fatal consequences. Specifically, data from the U.S. Army Safety Center demonstrates that fatigue is involved in 4% of Army accidents (Caldwell & Gilreath, 2002), and statistics from the Air Force Safety Center demonstrate that fatigue, at least in part, is attributed to 7.8% of Air Force Class A mishaps (Luna, 2003). Furthermore, 25% of the Air Force’s night tactical fighter Class A accidents from 1974 to 1992 were attributed to fatigue, and 12.2% of the Navy’s total Class A mishaps from 1977 to 1990 were thought to be the result of aircrew fatigue (Ramsey & McGlohn, 1997). Fatigue is an operational problem that demands attention in order for our warfighters to sustain lethality and safety.

Fatigue effects are the “largest identifiable and preventable cause of accidents in transport operations” (Akerstedt, 2000, p. 395). Efforts to mitigate their devastating effects have been in place for decades. The efforts range from generating operational sleep/wake schedules (Hursh, Redmond, Johnson, Thorne, Belenky, Balkin, et al., 2004) to real-time monitoring of the state of the operator (Wilson & Russell, 2003). One major
problem with current efforts to standardize operations for fatigue-related safety measures is individual differences. For example, some studies have found that fatigue leads to extreme performance decrements following sleep deprivation (e.g., Babkoff et al., 1985; Thorne, Genser, Singe, & Hegge, 1983) while others have found little change in performance after 48 hours of sleep deprivation (Belenky, Balkin, Krueger, Headley, & Solick, 1986). Cutting-edge mixed-effects modeling techniques have recently become available to model individual differences in the temporal dynamics of fatigue and performance (Van Dongen, Maislin, & Dinges, 2004). A recent study that assessed the degree of individual level variability in fatigue over time revealed an intraclass correlation coefficient (ICC) of .58 (Van Dongen, Maislin, & Dinges, 2004). This means that 58% of the variability in cognitive performance tested at increasing fatigue states is due to unknown individual level factors. Van Dongen, Maislin, and Dinges (2004) suggested, based on this finding, that variability due to individual differences is predictive rather than due to noise and that future efforts to model the effects of fatigue MUST include individual difference factors.

Classic fatigue studies (Ash, 1914; Bills, 1931) have demonstrated that reaction time variability increases may be predictive of performance decrements because fluctuations in reaction time increases prior to and after a decrement in average reaction time performance. In addition, sporadic high reaction time occurrences (mental blocks) have been shown as fatigue reaches high levels (Bills, 1931). One objective of the present research was to explore changes in performance trajectories over a 48 hour period of continued wakefulness and to see if such changes were predictive of performance on a high fidelity combat simulation. Specifically, accuracy, reaction time variability, and
mental blocks were analyzed in order to locate the emergence of strategic shifts in behavior as a function of increasing fatigue levels. In addition, stress appraisals and affect were explored as possible determinants of these individual differences. The tests selected to be examined for the proposed hypotheses demand cognitive functions that degrade as a function of fatigue and that are typically critical for military operations (O’Donnell, Moise, & Schmidt, 2005). These include rapid decision making and strategic planning.

Stress appraisals were explored as possible determinants of individual differences in fatigue effects. If the reduction in resources available to the individual due to fatigue no longer exceeds task demands and the individual has the perception of the inability to achieve a goal state, negative affect should emerge and performance should be inhibited (Zohar, Tzischinsky, Epstein, & Lavie, 2005). If this reduction in available resources continues to exceed the demands of the task and the ability to reach a goal state is attainable through compensatory efforts, performance should be sustained (Zohar, Tzischinsky, Epstein, & Lavie, 2005). Furthermore, the level of negative affectivity associated with a threat appraisal is expected to intensify the decreasing performance effect (Schneider, 2004).

Negative affect is further explored as a factor that differentially influences performance depending on the specific type of negative affect under investigation. Because negative affect has largely been investigated as a product of fatigue and little information is available in regards to how different types of negative affect may influence performance under sleep deprivation, hypotheses regarding this area are theoretically based. First, the theory of self-regulation is explored, which supports general performance claims that anxiety functions as a threat to the individual and produces
distraction leading to inhibitory effects on performance (Lerner, Dahl, Hariri, & Taylor, 2007). Such feelings of anxiety are accompanied by increased levels of cortisol, cardiac reactivity, and an “avoidance” response to stress. In addition, feelings of hostility can function to facilitate performance by narrowing one’s attention to the task, generating an “approach” response to stress with decreased cortisol levels and cardiac reactivity. A second explored possibility is that of performance-arousal theory and the inverted-U hypothesis where anxiety can function as an “incentive” and interact with the inhibitory effects of fatigue to facilitate performance through the narrowing of attention (Matthews, Davies, Westerman, & Stammers, 2000).

This research was conducted on active duty soldiers. First, a literature review of the effects of sleep deprivation on performance will be presented followed by a discussion of individual differences in fatigue vulnerability. Second, the stress appraisal process will be reviewed in the context of self-regulation theory. Third, possible links between differential types of negative affect, fatigue, and performance will be explored. Finally, a detailed review of results is presented in the context of the proposed models, followed by a discussion of findings and implications for military research.
II. BACKGROUND

Fatigue

The Effects of Continued Wakefulness on Cognitive Performance

In general, the negative effects of fatigue on performance include increased distraction, lack of creativity, decreased calculation abilities (Boff & Lincolin, 1988), lack of short-term memory abilities (Johnson, 1982), inflexibility and rigidity in problem solving behavior (Van der Linden, Frese, & Meijman, 2003; Van der Linden, Frese, & Sonnentag, 2003), and decreased alertness, perceptual sensitivity, increased reaction time, and decreased accuracy (Hockey, 1983). In addition, individuals have been found to switch to fast, less accurate strategies under early stages of fatigue (Shingledecker & Holding, 1974).

A variety of studies indicate that after 48-72 hours without sleep, soldiers become militarily ineffective. This is particularly true for more cognitive operations as opposed to physical operations (Belenky, Balkin, Krueger, Headley, & Solick, 1986). For example, a 72-hour laboratory-based sleep deprivation study conducted at the Walter Reed Army Institute of Research (WRAIR) (Babkoff et al., 1985; Thorne, Genser, Singe, & Hegge, 1983) showed that subjects took twice as long to complete laboratory tasks toward the end of the experiment than at the beginning. In addition, they found a 25% decrement in performance for every 24 hours of sustained operations. However, a field study conducted by the Human Resources Research Organization (HumRRO) (Ainsworth & Bishop, 1971) showed that tank crews were able to perform the communication, driving, surveillance, gunnery, and maintenance tasks without serious performance decrements during a 48-hour period without sleep, though reaction time was somewhat affected (Belenky, Balkin, Krueger, Headley, & Solick, 1986). Furthermore, in a study of
continuous work for 54 hours conducted by the Defense and Civil Institute of Environmental Medicine (DCIEM) (Angus & Heslegrave, 1985), psychomotor performance decrements of 40% of baseline were found after 48 hours of continuous work where two peaks of degradation were found after 18 hours, and again after 24 hours suggesting a circadian trough effect. These studies indicate that soldiers can remain effective for up to 48 hours of sustained operations with the exception of cognitive deficits occurring after 24 hours (25%), especially in reaction time.

Ash (1914) discovered that the area of mental fatigue has exhibited parallels to the process of physical fatigue. The classical fatigue curve demonstrated by Ash (1914) shows increased variability in reaction time prior to and after a decrement in performance when observed over time. Other mental fatigue phenomenon includes the blocking effect, reported by Bills (1931). This effect was operationalized by Welford (1980) as an instantaneous reaction time occurrence that is greater than 2 times the mean reaction time in a series of responses. Holding (1983) and Welford (1980) reported that mental fatigue over time exhibits increasingly sporadic reaction times, and suggests two explanations: increased noise in the system or decreased executive functioning. They noted that changes in behavior following fatigue occur to different degrees and do not occur for everyone. However, Guastello (1995) claims that nonlinear models that incorporate performance shifts, such as changes in reaction time variability, are better equipped to represent such individual level behavior.

Consistent with the belief that fatigue leads to decreased control of neural processes, one particular study highlighted specific cognitive difficulties that are of particular interest to the current research objectives. Van der Linden, Frese, and
Meijman (2003) analyzed the behavioral manifestations of fatigue, operationalized as 2.5 hours of consecutive task participation, and found them to be linked to executive control. In this study, executive control was operationalized as flexibility and planning. Flexibility was measured using the Wisconsin Card Sorting Task. These researchers found that fatigued subjects displayed more perseverative errors (non-systematic error) when compared to non-fatigued subjects. Perseverative errors are related to a task-switching deficit where participants continue to respond to a learned criteria rather than switch to a new criteria when the task changes. This finding is consistent with Thayer and Friedman’s (2002) proposition that the ability to inhibit a learned response is a functional element in the self-organization of living dynamical systems. Planning was measured using the Tower of London test. The results indicated that fatigued subjects consumed more planning time than non-fatigued subjects. These researchers concluded that fatigue leads to suboptimal performance levels by compromising one’s ability to carry out executive control. Moreover, Larsen (2001) found that in a sample of sleep deprived military students, the majority of participants continued to fire at dummy targets that were suddenly replaced by human beings (dummy cartridges replaced live ammunition without participant knowledge).

Van der Linden, Frese, and Meijman (2003), quoting Goschke (2000, p. 331), stated that through executive control humans are able to “…transiently couple almost any response to almost any stimulus, even when there are neither innate nor acquired connections between stimulus and response.” This statement is similar to Carver and Scheier’s (1991) explanation of the self-regulation process. Carver and Scheier (1991) explain that behavioral scripts can become active through the conscious development of
intent. When functioning under this goal-behavior status, behavior conforms to meet higher-order goals through a processes of feedback control. Van der Linden, Frese, and Meijman (2003) also concluded that it is not the mental representation of the goal itself that is affected by fatigue; rather, it is the activation level through which the goal can influence behavior that is reduced. Where goal-directed behavior is less capable of constraining lower-order behavior due to fatigue, automaticity may increase rendering the actor dependent on practiced behavior.

Consider the following passage in Juarrero’s (1999) seminal publication:

“…proximal intentions are dynamical attractors that function as top-down control operators entraining other subsystems, including motor control. These second-order contextual constraints restrict some of the motor subsystems’ potential as these become entrained to the intention’s organization” (p. 192). Juarrero (1999) further explains that second-order constraints drive behavior in a particular direction because they are changes in the frequency distribution of entrained motor processes. The objective of the present research was to identify the effects of fatigue on the self-regulatory behavior of the cognitive performer. With consideration of Carver and Scheier’s (1991) view of self-regulation as well as Juarrerro’s (1999) view of behavior, it was expected that fatigue would disrupt the ability of top-down process to properly constrain lower-level processes to follow the trajectory of intention. If this speculation is true, reduced performance on tasks that demand these executive functions should be revealed as fatigue levels reach noncompensatory levels. Moreover, metrics such as reaction time variability and mental blocks are of particular interest. However, to assume such a linear effect is naive.

Circadian variations alone operate in a nonlinear fashion (Holding, 1983). In addition,
other factors such as motivation and alertness (Hull, Wright, & Czeisler, 2003) as well as challenge appraisals (Schneider, 2004) may preserve top-down control over second-order contextual constraints. Such individual difference factors may lead to compensatory behavior, yielding response parameters that are qualitatively different than baseline response parameters.

**Individual Differences in Fatigue Vulnerability**

Caldwell and several colleagues (2005) state that the factors which underlie individual differences in fatigue vulnerability are presently unknown. Upon reviewing the limited literature in this topic area, these authors concluded that the ability to sustain performance under sleep deprivation is a stable trait, where an individual considered “fatigue vulnerable” will be vulnerable each time he/she is exposed to fatigue (Mallis et al., 2001; Morgan, Winne, & Dugan, 1980; Van Dongen, Baynard, Nosker, & Dinges, 2002). Blasgrove and Akehurst (2001) reported that neurotic extraverts are more susceptible to sleep deprivation effects because they are vulnerable to decreases in mood and are more affected by external stressors. Killgore, Richards, Killgore, Kammimori, and Balkin (2007) explained that extraverts may perform more poorly under fatigue due to their lower baseline levels of cortical activation and the demand for more external stimulation to maintain optimal performance. This idea is consistent with Caldwell’s (2005) finding that baseline cortical activation is predictive of fatigue vulnerability. Along similar lines, Hill, Welch, and Godfrey (1996) found that those who exhibited an external locus of control revealed significant decreases in mood after exposure to 24-30 h of sleep deprivation. Negative affect did not increase for those who exhibited an internal locus of control. In addition, Verwey and Zaidel (2000) found that sleep deprived
externals produced significantly more errors on a driving simulator task when compared to internals. Summarizing this literature, individuals who have an internal focus appear to be less vulnerable to fatigue, due to either higher baseline cortical activation, the ability to resist decreases in mood, or the ability to compensate for increasing task demands.

Rather than investigate these potential subject “trait” factors that are speculated to predict fatigue vulnerability, the present research examined the ability of subject “state” factors to predict changes in performance as a function of sleep deprivation. Specifically, affect and stress appraisals, which contribute to the process of self-regulation (Carver & Scheier, 1991), were examined. It was hypothesized that the ability to utilize self-regulatory efforts (such as changes in affect, stress appraisals, or in performance strategy), under continued wakefulness would underlie such differences in fatigue vulnerability.

Affect, Stress Appraisals, and Performance

Fatigue decreases cognitive ability (e.g., Boff & Lincoln, 1988; Lieberman, et al., 2005; Matthews, Davies, Westermen, & Stammers, 2001) and increases negative affect (Lieberman, et al., 2005; Thorne, et al., 1983). According to Zohar, Tzischinsky, Epstein and Lavie’s (2005) Cognitive-Energy Model, demanding circumstances require effortful self-regulation and the levels of energy available for behavioral self-regulation will influence the intensity of emotional reactions. These authors speculate that emotion is a product of an evaluation of progress toward goal-behavior. If progress is made despite the presence of environmental stressors, positive affect will result. If progress is not made, negative affect will follow. In support of Carver and Scheier’s (1991) theory of self-regulation, Zohar, Tzischinsky, Epstein, and Lavie (2005) explain that this occurs
through a process called a stress appraisal. During the stress appraisal process, the amount of resources available to reach a goal state are evaluated, if goal attainment is feasible then positive affect results, otherwise negative affect results.

Specifically in the event of stress, an appraisal would be defined as an evaluation of a [stressful] situation that has implications for a person’s beliefs, values, or goals (Lazarus & Folkman, 1984). In general, two types of appraisals are theorized: primary and secondary (Lazarus & Folkman, 1984). A primary appraisal consists of the initial evaluation of whether one’s resources are threatened and whether the imposing stressor has the likelihood of being challenging or threatening to the individual. The secondary appraisal involves the assessment of resources or coping mechanisms available to either reduce the negative effect or improve the positive effect of the stressor. According to the transactional model of stress, the primary appraisal or evaluation phase is context specific (Lazarus & Folkman, 1984). Context specificity implies a dependency on initial conditions that are present in the environment and in the person. A situation that is deemed threatening to the individual coupled with the belief that the individual does not have the resources available to cope with the stressor is theoretically called a “threat” appraisal (Lazarus & Folkman, 1984) and can be viewed as “an avoidance” to the situation (Arnold, 1960). In contrast, a stressor that produces a stimulating reaction coupled with the evaluation of available resources is theoretically called a “challenge” appraisal (Lazarus & Folkman, 1984) and can be viewed as “an approach” to the situation (Arnold, 1960). Threat appraisals are associated with negative affect, and perceptions of low control over the stressful event, whereas challenge appraisals are associated with positive affect, moderate levels of negative affect and a sense of control over the stressful
event (Schneider, 2004).

Generally, individuals who perceive a task as challenging show more healthy cardiac responses (increased cardiac output coupled with decreased total peripheral resistance) and perform significantly better on cognitive tasks than those who perceive the task as a threat (Schneider, 2004; Tomaka, Blascovich, Kelsey, & Leitten, 1993). This performance differentiation has also been generalized to training performance where differences remained stable throughout the training exercise (Gildea, Schneider, & Shebilske, 2007). The effect that appraisals can have on stress and performance can be best explained within the context of a closed-loop model of stress (Wickens and Hollands, 2000) based on concepts proposed by Lazarus and Folkman (1984) and Hockey (1997). This model is presented in Figure 1.

![Closed-Loop Model of Strategic Control](image)

**Figure 1.** Closed-Loop Model of Strategic Control (Wickens & Holland, 2000).

Figure 1 demonstrates how individuals practice strategic control in the event of a stressor. The model shows that the response of the individual is dependent on the stress appraisal and the level of control the individual attributes to the task. Depending on this appraisal, individuals may 1) allocate more resources to the task, 2) remove the stressor,
3) apply a different strategy to the task, or 4) do nothing. Thus, appraisals can affect performance through choices in strategic control in the event of a stressor. Each decision has different implications for performance. For example, allocating more effort to the task can stabilize performance levels, but at the expense of physiological costs (Wickens & Holland, 2000). Changing the nature of the task can reduce working memory demands by allowing the person to revert to less effortful strategies. However, less effortful strategies lead to more automatic or learned behaviors that could improve or inhibit performance (Hanoch & Vitouch, 2004; Larson, 2001). Less effortful strategies mostly involve faster, less accurate responding under fatigue (Boff & Lincoln, 1988). Eliminating the stressor can be effective in stabilizing performance only if removing the stressor does not change the nature of the task. Finally, doing nothing will lead to reduced performance. Speculating, a challenge appraisal could lead to the allocation of more resources to the task or a strategic shift in control. The psychological effects of stress can be productive when they move the individual toward a goal state by narrowing attention to relevant features of the task (Hanoch & Vitouch, 2004).

In contrast, a threat appraisal could lead to either poor strategic shifts that are unsuccessful in sustaining performance or to the person doing nothing. As Hancock and Warm (2003, p.18) stated, “The worst stress situation is one where there are high demands and the person attributes a lack of control to the task.” Schneider (2004) found that threatened individuals tend toward increased negative affectivity as stressors unfold. Because affect is viewed as a product of the stress appraisal process, and since fatigue has been shown to deplete top-down self-regulatory capabilities, it is hypothesized that
negative affect will increase as fatigue levels increase due to the assessment of limited resources and that positive affect will decrease as fatigue levels increase.

The story of negative affect and performance is much more complicated since challenge appraisals are also associated with moderate increases in negative affect (Schneider, 2004). Until recently, negative affect was investigated as a composite emotion and speculations regarding negative affect and performance under the influence of fatigue have not been studied in as much detail as the relationship between fatigue and negative affect. When viewed as a composite “negative affect,” it is generally believed that performance will deteriorate due to distracting thoughts and inhibited motivation that generally follow from negative feelings (Davis & Nolen-Hoeksema, 2000; Lerner, Dahl, Hariri, & Taylor, 2007; Zohar, Tzischinsky, Epstein, & Lavie, 2005). However, physiological evidence shows that some individuals respond differently to negative affect (Lerner, Dahl, Hariri, & Taylor, 2007). Feelings of anger and disgust, revealed through facial expressions, are associated with decreased cortisol and cardiac reactivity, while feelings of anxiety are associated with increased cortisol and cardiac reactivity (Lerner, Dahl, Hariri, & Taylor, 2007). These authors discuss this affect dichotomy in the context of self-regulation theory speculating that anger and disgust may lead to a sense of control over the situation causing individuals to approach a task with more vigor. In contrast, anxiety will produce distracting thoughts and a lack of control leading to an avoidance of a task. In addition, depression leads to feelings of rumination, or a prolonged negative mood experience, that causes attention to focus more on the emotion and less on the task (Davis & Nolen-Hoeksema, 2000). Research has demonstrated that individuals categorized as “dysphoric,” who tend to ruminate more following a depression episode,
also exhibit more cognitive inflexibility operationalized as more perseverative errors (Davis & Nolen-Hoeksema, 2000).

Negative affect viewed in this way complements the threat-challenge dichotomy. Specifically, those who respond to increases in task demands with anger or disgust may have experienced challenge appraisals, while those who respond to increases in negative affect as anxiety may have more of a threat response. When viewed in the context of self-regulation theory, Figure 2 presents the layout of possible performance outcomes as a function of stress. The current study will investigate hostility (rather than anger and disgust), anxiety, and feelings of depression.

![Figure 2](image)

*Figure 2. Adaptation of Wickens and Holland’s (2000) model of strategic control under stress.*

The above figure illustrates that anxiety and depression, as a product of a threat appraisal, may further deplete the resources available to the individual and ultimately lead to poor performance (Davis & Nolen-Hoeksema, 2000; Lerner, Dahl, Hariri, &
Taylor, 2007). In addition, it is expected that positive affect will be reduced due to the perception of the lack of resources available to meet the demands of the task (Zohar, Tzischinsky, Epstein, & Lavie, 2005). Also illustrated is that either the maintenance of positive affect or hostility, as a product of the challenge appraisal, may lead to effective performance shifts, such as shedding less critical tasks (Lerner, Dahl, Hariri, & Taylor, 2007; Zohar, Tzischinsky, Epstein, & Lavie, 2005). This adapted version of Wickens and Holland’s (2000) model incorporates the modulation of emotions as a function of threat and challenge appraisals, while also accounting for the differentiating effects of negative affect on performance as found by Lerner, Dahl, Hariri, and Taylor (2007).

**Fatigue, Stress Appraisals, Affect, and Performance**

An important focus of this research is to investigate how fatigue interacts with the appraisal-performance process. The interaction of fatigue and the stress appraisal process (assessment of available resources versus task demands) was tested and it was expected that as fatigue increased the perception of available resources would diminish due to reduced executive control over increasing task demands (Van der Linden, Frese, & Meijman, 2003; Van der Linden, Frese, & Sonnentag, 2003). In addition, it was expected that fatigue would lead to increases in negative affect (Lieberman, et al., 2005; Thorne, et al., 1983) What is less clear and uninvestigated according to current literature and is the interaction of fatigue and emotional modulation, with consideration of differentiating negative affect components.

Traditional research speculates differently in regard to anxiety and performance. When anxiety is viewed as “arousal,” it becomes an incentive (Matthews, Davies, Westerman, & Stammer, 2001). This is precisely what Hanoch and Vitouch (2004)
discuss when challenging the inverted-U hypothesis stating that high arousal may sustain performance by narrowing attention toward the task. They explain this phenomenon as an ecological survival response to stress and claim that further research needs to investigate the high arousal side of this inverted-U. Under sleep deprivation, anxiety or “threat” functions as an incentive that drives motivation and approach toward the task when the lack of motivation exists otherwise under fatigue (Matthews, Davies, Westerman, & Stammers, 2000). In this case, anxiety alone should inhibit performance due to its distracting properties, but in combination with fatigue (a non-stimulating stressor), it facilitates performance. According to Hancock and Warm’s (2003) dynamic model of the inverted-U arousal-performance trend, anxiety should function to interact with fatigue by sustaining performance as long as the level of anxiety remains in the individual’s “zone of adaptability.” This more traditional view of the interaction between anxiety and fatigue in combination with Hanoch and Vitouch’s (2004) view of anxiety functioning as an ecological survival tactic would suggest that as fatigue increased, associated increases in anxiety may function to sustain performance. Figure 3 represents the interaction between fatigue and the emotional response of anxiety. Because there is no evidence that depression interacts in the same way as anxiety with fatigue, it remains viewed as an inhibitor of performance as found by Davis and Nolen-Hoeksema (2000).
Summary of Research Questions

The present study focused on identifying factors that contribute to the ability to sustain performance on a stressful task under continued wakefulness. First, individual difference factors were examined for their ability to account for performance differences that emerge due to fatigue. Specifically, accuracy, reaction time variability, and attention lapses were investigated. Second, stress appraisals were assessed for their ability to predict performance decrements. Negative affect was then investigated as a single construct followed by analyses of anxiety, depression, and hostility and performance separately. Particular emphasis will be placed on the models presented in Figure 2 and Figure 3. For purposes of clarification, the first model (adaptation of Wickens and Holland’s model) will be called the Adapted Stress Appraisal Model and the second model will be called the Fatigue Arousal Model. The specific hypotheses under investigation include:
Attack Combat Simulation Performance

H1. The number of enemy kills (as the primary dependent variable for the combat simulation) will significantly decrease as a function of fatigue.

H2. Friendly fire, mine kills, and casualties (as secondary dependent variables for the combat simulation) will significantly increase as a function of fatigue.

Synthetic (Micro-level) Task Performance

H3. Rapid decision making percent correct will decrease as a function of fatigue (Hockey, 1983).

H4. Rapid decision making reaction time variability and “misses” or attention lapses will significantly increase as a function of fatigue prior to significant decreases in percent correct (Ash, 1914; Bills, 1931). In other words, if a decrease in accuracy is seen at 24 h of sleep deprivation, significant increases in variability and misses may occur at 18 h of sleep deprivation.

H5. Tower of Hanoi solution time will significantly increase as a function of fatigue (Van der Linden, Frese, & Meijman, 2003).

Stress Appraisals

H6. Stress appraisals will significantly increase as a function of fatigue, due to the assessment of unavailable resources, as indicated by more individuals being categorized as threatened (Van der Linden, Frese, & Meijman, 2003; Van der Linden, Frese, & Sonnentag, 2003).
H7. High stress appraisals will be associated with decreases in performance for both the combat simulation performance metrics and the synthetic cognitive performance metrics (Schneider, 2004; Tomaka, Blascovich, Kelsey, & Leitten, 1993).

**Affect**

H8. Positive affect will significantly decrease as a function of fatigue (Zohar, Tzischinsky, Epstein, & Lavie, 2005).


H10. The following hypotheses were more exploratory in nature due to the limited information available to generate sound predictions (negative affect as a composite factor is not expected to account for decreases in performance). Either:

   H10a. Higher scores on anxiety and depression will predict poor performance, while higher scores on hostility will predict either sustained or improved performance as a function of fatigue (Davis & Nolen-Hoeksema, 2000; Lerner, Dahl, Hariri, & Taylor, 2007).

   H10b. Increases in anxiety will be associated with performance sustainment or improvement under sleep deprivation (Matthews, Davies, Westerman, & Stammer, 2001).
III. METHOD

The present research aimed to identify factors that explain or predict individual differences in fatigue vulnerability on performance of a high fidelity immersive environment attack combat mission over a continued wakefulness profile. The factors of interest for the present study included two cognitive performance tasks (rapid decision making and spatial move planning), stress appraisals, and negative affect (anxiety, depression and hostility subscales). Using the following experimental design, we explored the ability of these factors to explain fatigue vulnerability.

Participants

A total of 18 male volunteers with basic infantry skills and recent qualification with any small arms were recruited for this study. Participants were recruited from the 16th and 143rd Ordinance Battalion located at the Aberdeen Proving Ground, Maryland. Permission to release the soldiers from duty to participate in this study was coordinated between the Army Research Laboratory of Aberdeen Proving Grounds and the Battalion Commander Sergeant Major. All participants were screened for normal or corrected-to-normal visual acuity and normal color vision via examination with the Titmus II Vision tester. In addition, participants’ hearing was screened at a level of 20 db HL at octave frequencies 500 through 4000 Hz using a portable audiometer. All participants displayed normal or corrected-to-normal visual acuity (20/30), normal color vision, and normal hearing levels.

All participants were briefed on the purpose and procedures of the study and given ample opportunity to ask questions and voice concerns prior to signing for voluntary consent. Potential volunteers were given the required brief regarding
confidentiality as indicated on DA Form 5303-R. Upon acquiring informed consent, visual and hearing screening was performed.

_Instruments and Apparatus_

Psychological Measures

_**Stressor Appraisal Scale (SAS).**_ The SAS (Schneider, 2008; Appendix B) is a ten-item questionnaire designed to assess cognitive appraisals of stressors. The questions target primary and secondary appraisals as they pertain to an impending stressful task. The SAS assesses both primary stress appraisals (7 items; alpha = .78) as well as secondary stress appraisals (three items; alpha = .89). The scale allows for all ten items to collapse into a ratio (task demand/available resources) where higher scores denote threat. The SAS was found to be reliable as well as valid in previous research demonstrating physiological and behavioral discrimination of challenged and threatened individuals (Schneider, 2008). Items are rated on 7-point Likert scales.

_Multiple Affect Adjective Checklist – Revised._ The Today form of the Multiple Affect Adjective Checklist – Revised (Appendix C; MAACL-R; Lubin & Zuckerman, 1999) was administered to assess state affect. Because of the improved discriminant validity and the control of checking the response set, the MAACL-R Today has been found to be particularly suitable for investigations which postulate changes in specific affects in response to stressful situations. This form consists of a list of 132 adjectives in which participants are instructed to check all those words describing how they “feel right now,” or “during the mission or test they just completed.” The MAACL has five validated subscales: anxiety, depression, hostility, sensation seeking, and positive affect. The State version of the MAACL-R demonstrated high internal reliability scores (alphas)
in a sample of 1,392 Air Force personnel (Lubin & Zuckerman, 1999). Specifically, these scores include anxiety (.84), depression (.83), hostility (.91), dysphoria (combination of hostility, anxiety, and depression; .91), and positive affect (.89). In addition, construct, convergent, and discriminant validity were all demonstrated in comparison to the State-Trait Personality Inventory (Lubin & Zuckerman, 1999). Administration time for the MAACL-R is approximately one minute.

Cognitive Measures

Army Cognitive Readiness Assessment Battery. The following tests were selected by utilizing the T-Matrix Methodology (see O’Donnell, Moise, & Schmidt, 2004 for a detailed explanation). T-Matrix values (indication of how much each test demands a certain level of various cognitive functions) are mapped to the cognitive demands of the virtual attack combat scenario. Included are six tests called the Army Cognitive Readiness Assessment (ACRA) Battery: Attack Mission. For purposes of the present study, only two of these six tests were examined in detail due to their demand of executive control. The two tests include the Rapid Decision Making test and the Tower of Hanoi Puzzle. See Appendix D for a complete description of each test, including scoring.

Rapid Decision Making. The Rapid Decision Making test requires one to assess the threat of a situation based on multiple dimensions and to react quickly based on this assessment. From the highest commander to the lowest ranking soldier, the battlefield imposes intrinsic limitations on the quality of information received. Decisions and actions must take place rapidly under uncertainty concerning multiple factors (e.g., enemy movements, positions, capabilities, and intentions compound with conditions of smoke, geography, and deliberate confusion from
the enemy). The Rapid Decision Making test replicates the situation where the soldier must select approaching enemy targets among uncertain targets (questionable civilians) and friendlies, while also assessing their levels of threat based on proximity.

*Tower of Hanoi.* The Tower of Hanoi involves the ability to plan strategic steps toward a specific goal. This test also requires planning a sequence of steps when the initial sequence can no longer be used due to a wrong move. This skill would apply to a navigating situation where a wrong turn occurred somewhere in the path, as well as any other activity where strategic planning is required. The current study focused on the 3-disk version of the Tower of Hanoi (See Appendix D for details).

**Test Facility and Stimuli**

*Tactical Environment Simulation Facility* (TESF) at the Army Research Laboratory, Aberdeen Proving Grounds, Aberdeen, MD. The TESF is equipped with the Fakespace Systems RAVE II® Immersive Environment Simulator (IES), which provides a reconfigurable immersive stereoscopic display consisting of three 10’ x 12.5’ screens. The video displays were used in conjunction with an immersive sound system consisting of 44 loudspeakers.

*Tom Clancy’s Rainbow Six 3 Raven Shield* (Ubi Soft Entertainment, Montreuil-sous-Bois, France). Raven Shield is a computer generated, first person shooter game that has inherent militaristic capabilities and programmable features. The Raven Shield simulation is shipped with an environmental editor that resembles a Computer Aided Design (CAD) package, allowing the editing and creation of virtual environments.
This study utilized a virtual replication of the McKenna MOUT site located at Ft. Benning, GA. The McKenna environment was created using the built-in Raven Shield editing tool. The virtual MOUT site features fully functional architectural components (i.e., opening doors, stairs, etc.). In addition, each test participant was equipped with a 6.4” LCD for the display configuration. The display configuration is a 2-D configuration providing a top down digital map of the McKenna MOUT site. An example of the 2-D terrain map is shown in Figure 4.

![Example snapshot of 2-D configuration.](image)

*Figure 4.* Example snapshot of 2-D configuration.

The specific task designed for the purposes of this study was called Operation Flashpoint. Participants were tasked to clear several buildings while destroying enemy targets along the way. Each test trial consisted of 20 min. of video game play. During each test session, participants completed two test trials. One trial was performed under standard noise conditions, that is, the individual only heard those sounds inherent to the game (foot fall, breathing sounds, rifle fire, etc) via headphones. The other trial was performed under conditions of combat noise (artillery and mortar fire, impact sounds, etc) as produced by the TESF speaker array (the noise manipulation was specific to the
objectives of the Army Research Laboratory\textsuperscript{1}). The order of presentation (standard vs. battlefield noise) was counterbalanced. Standard noise was presented via headphones and generated by the video game program. That is, for purposes of this study, background sounds that are those inherent to the game (foot falls, enemy or one’s own rifle fire, etc) are considered standard noise. The battlefield noise was produced by the speaker array located in the TESF. These sounds consisted of artillery and mortar firing, impacts sounds, and armored vehicle noise that are part of the HES sound library. The battlefield noise was presented on top of the standard game noise. Battlefield noise levels varied, but were maintained below the maximum safety levels and allowable daily levels determined by the Occupational Safety and Health Administration (OSHA, 1983) and the U.S. Army Standard (DA PAM-40-501R with addenda). An example of the participant’s view from an “Aim” and “Fire” preparation is shown in Figure 5.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure5.png}
\caption{Participant “Aim” and “Fire” presentation during Operation Flashpoint.}
\end{figure}

The Flashpoint attack combat simulation recorded four performance measures. The primary task for participants was to engage enemy targets during a clearing mission of a

\textsuperscript{1} The Human Research Effectiveness Directorate and the University of Central Florida (UCF) collected data during this study independently of ARL. For purposes of providing a complete overview of the sequence of events, Figure 6 displays the schedule of ACRA/attack combat scenario (Raven) presentation in addition to blocks of time required for the HRED test procedures (G-8 & Shoot).
war site (enemy kills). Secondary, nonetheless important, variables included avoiding lethal mines (mine kills), holding fire to civilians (friendly fire), and maintaining survival (casualties).

Procedure

Data collection began on the same day as the pre-brief. Once voluntary consent was acquired, participants were asked to submit to the vision and hearing screening as well as complete a series of questionnaires. The Titmus II Vision tester was used for vision screening and a MAICO, Model Ma-14 portable audiometer was used to screen hearing threshold levels. In order to obtain a baseline measure of affect, the MAACL-R was administered.

The first day of the study was a training day. Individuals were trained on the cognitive assessment battery (ACRA) and on the attack combat simulation. Testing began on day 2 in building 459 of the Human Research Effectiveness Directorate and continued for 36 hours (participants were released early due to the inability of participants to maintain wakefulness). The total time commitment of this study (including travel time and training) was 61 hours with 36 hours of continuous operation. All required transportation to and from the soldiers’ duty station was provided by Human Research Effectiveness Directorate personnel of Aberdeen Proving Grounds who also utilized government-owned vehicles.

Training on both ACRA and Operation Flashpoint was conducted concurrently. Participants were trained in three groups of six. Training was limited to six individuals at a time on the ACRA due to computer constraints. For purposes of training, ACRA was presented on laptop computers and desktop computers (all participants received at least
one training session on a laptop) and Operation Flashpoint was presented on desktop computers. A specific training schedule was not followed for the ACRA and the Operation Flashpoint; rather, certain training criteria had to be met for each test. Each participant completed six sessions of the Tower of Hanoi and the Rapid Decision Making Test during training. Each complete ACRA session took approximately 30 minutes to complete.

The attack combat simulation training (Operation Flashpoint) was conducted in three phases. The first phase focused on mastering virtual combat skills via keyboard and mouse interactions with the virtual environment and took approximately 30 to 40 minutes. The second phase focused on establishing familiarity with the virtual McKenna MOUT site and took approximately 30 to 40 minutes. The third phase was set up and run like an actual test trial (using inherent game noise only). Each participant repeated a mission until successful. Success was achieved when the soldier killed all enemy targets and met the objective of clearing a building. This phase took approximately one hour.

Prior to the beginning of the 48-hour continued wakefulness period, participants were randomly divided into six groups of three (only three laptop computers were available for testing). Participants were instructed to record food and drink products that were consumed throughout the data collection period (See Appendix E). Individuals remained in their group throughout the study. The sequence of events for each group of three was identical and is displayed in Figure 6.
Figure 6. Forty-eight hour test schedule.

Testing began at 1900 on day one with the administration of the ACRA.

Specifically, all participants were tested for the first time in a 6-hour period of time with 3 participants tested per hour. Thus, session 1 occurred during a range of 0-5 hours of sleep deprivation. The list below details the amount of sleep deprivation that is defined by each testing session.

- **Session 1**: 0 – 5 hours of sleep deprivation
- **Session 2**: 6 – 11 hours of sleep deprivation
- **Session 3**: 12 – 17 hours of sleep deprivation
- **Session 4**: 18 – 23 hours of sleep deprivation
- **Session 5**: 24 – 29 hours of sleep deprivation
- **Session 6**: 30 – 35 hours of sleep deprivation
Following ACRA, the attack combat scenario was presented to each participant on a 10’ x 12.5’ stereoscopic screen. Each participant completed two 20-minute trials of video game play under conditions of standard noise and battlefield noise (counterbalanced to control for order effects). The MAACL-R was administered prior to and subsequent to the completion of attack combat scenario and prior to the ACRA. The SAS was administered prior to the administration of the ACRA and prior to each attack combat scenario.
IV. DATA ANALYSIS

Means and standard deviations are presented in Table 1 for all variables of interest in this study. One participant’s data was excluded from all analyses due to speculations that the individual received rest between 2 testing sessions. This individual revealed substantially low scores on the ACRA tests during one of the testing sessions (e.g. 3.1 percent correct on the Rapid Decision Making Test), and performed optimally during the next set of combat simulation tasks (45 minutes occurred between these testing sessions). Therefore, the following analyses were conducted on 17 subjects rather than 18. In addition, the study was terminated after 36 hours due to the inability of the participants to maintain wakefulness.
Table 1

*Means (standard deviations) for study variables.*

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<th>Session 2</th>
<th>Session 3</th>
<th>Session 4</th>
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<td>Positive Affect Combat Simulation</td>
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<tr>
<td>Negative Affect Combat Simulation</td>
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34
**Modeling of Variables**

Mixed-model Analysis of Variance tests were conducted on each variable to test the hypotheses of the present study. This test is most appropriate when analyzing repeated measures data due to its nested structure and the ability to model data that exhibits correlated error and non-constant variability (SPSS, 2007). When performing a mixed-model ANOVA, it is important to model the covariance structure type that best fits the data. Each factor in the present study was tested for heterogeneity of variance by performing a chi-square test on the Schwartz's Bayesian Criterion (BIC) index provided in the analysis of both the scaled identity covariance structure type (assuming homogeneity) and the diagonal covariance structure type (assuming heterogeneity). Where BICs are significantly lower (a difference of at least 11.07) for diagonal covariance structures, heterogeneity is built into further analyses. Lower BIC values indicate better fit (Muthen, 2002). In addition, each factor was subjected to a test of autocorrelation, as was each dependent variable in the present study. Significant autocorrelation functions are revealed in a test of covariance parameters in the mixed-model ANOVA. Significant autocorrelation parameter tests call for autocorrelation to be built into further analyses. Dependent variables that exhibited both autocorrelation and heterogeneity were further tested under an autocorrelation-heterogeneity covariance structure (this was only the case for stress appraisals as assessed prior to the ACRA tests). A significance test is also available for this covariance structure type in the mixed-model ANOVA. See Appendix F for a list of the BIC values for the scaled identity, diagonal covariance structure type for each dependent variable, as well as the significance values.
for the auto-regressive correlation covariance structure type. Covariance structure types will not be reported later in this chapter for simplification.

*Flashpoint Attack Combat Simulation*

The Flashpoint attack combat simulation recorded four performance measures as dependent variables: Enemy kills, mine kills, friendly fire, and casualties. First, performance on the standard noise condition was compared to the battlefield noise condition. Paired-sample T-tests were conducted at each session in order to determine if the exaggerated “battlefield” noise manipulation resulted in significantly different performance from the standard noise condition. Results revealed no significant differences between conditions for each testing session. Because the noise manipulation was not effective in the present study, comparisons between the standard noise and the battlefield noise conditions were not made for the independent variables in the study. Rather than introducing more variability in the dependent measures by averaging the scores across the battlefield and standard noise conditions, only one of the conditions was selected for further analyses. Because it is believed that the battlefield noise condition would elicit more stress, the remainder of the analyses was conducted on the “battlefield” noise data only.

The next critical analysis examined fatigue effects on the primary task metric of enemy kills and the secondary task metrics of mine kills, friendly fire, and casualties. To test for fatigue sensitivity, a mixed-model ANOVA was performed on the dependent measures of enemy kills, mine kills, friendly fire, and casualties with each testing session as an independent, fixed factor. This analysis revealed significance only for the number of enemy kills, $F(1, 5) = 2.39, p < .05, \eta^2 = .10$ (see Figure 7). Post-hoc comparisons with
Bonferroni corrections revealed a significant difference only between session 4 ($M = 8.31, SD = 0.87$) and session 6 ($M = 6.06, SD = 2.93$), partially supporting hypothesis H1.

*Figure 7.* The number of enemy kills over continued wakefulness sessions.

Individual differences on the number of enemy kills over the sleep deprivation period were investigated. Figure 8 shows the scores across time for all participants.

*Figure 8.* Individual differences in enemy kills trends over continued wakefulness sessions.
Figure 8 illustrates that some individuals were able to maintain performance and may have even improved in the number of enemy kills over the continued wakefulness period while some individuals exhibited large decrements in performance. Figure 8 also shows that individual variability is even more pronounced during session 6, where performance is significantly lower for all participants as a group as compared to session 4, which appears to have less variability. This finding motivated the exploration of a natural break in performance for “stable” individuals where performance either did not change or improved over time (N = 8) versus “fatigue vulnerable” individuals where performance decreased as a function of fatigue (N = 9). Participants were rank ordered by calculating the difference in scores from the last testing session to the first testing session. Figure 9 illustrates the enemy kills performance dichotomy between stable and fatigue vulnerable individuals.

![Bar chart showing change in the number of enemy kills from session 1 to session 6 by group.]

*Figure 9.* Change in the number of enemy kills from session 1 to session 6 by group.
Next, performance trends for the two groups were mapped as a function of fatigue and are presented in Figure 10. It can be seen from these trends that the two groups almost performed equally throughout the entire experiment until session 6. Specifically, mixed-model ANOVA revealed a significant interaction, $F(5, 89) = 6.19, p < .001, \eta^2 = .28$. An Independent samples t-test revealed significant differences between groups during session 1, $t(15) = -2.72, p < .05$, and session 6, $t(15) = 5.37, p < .001$.

![Graph showing performance trends](image)

**Figure 10.** The number of enemy kills over continued wakefulness sessions: stable vs. fatigue vulnerable groups.

Secondary task performance was also evaluated to identify compensatory efforts of those individuals who were able to sustain performance. An assessment of the number of mine kills (the number of times the participant stepped on a deadly mine) revealed a significant interaction between group (stable vs. fatigue vulnerable) and session, $F(5, 89) = 2.68, p < .05, \eta^2 = .17$ (Figure 11a). However, post-hoc independent t-tests did not reveal any significant differences. In addition, a main effect for group was found for the number of casualties (number of times the participant was shot by enemy fire), $F(1, 23) = $
6.76, \( p < .05, \eta^2 = .21 \), with the fatigue vulnerable group performing significantly worse throughout the sleep deprivation period (see Figure 11b).

*Figures 11 a & b.* Number of (a) mine kills and (b) casualties: stable vs. fatigue vulnerable groups. 

In summary, the hypothesis that a decrease in enemy kills would occur as a function of fatigue was partially supported as performance was significantly lower at session 6 as compared to session 4 only. In addition, by classifying individuals based on differences in performance from session 1 to session 6, it was found that approximately half of the participants remained stable while other participants exhibited fatigue vulnerability. Because there are individual differences in performance, the next step is to investigate whether similar differences are found for other performance measures. The second hypothesis (H2) was also partially supported as the number of casualties were found to be related to poor performance as indicated by the significant main effect for group with the fatigue vulnerable group experiencing more casualties than the stable group. It was also found that the stable group had fewer mine kills throughout the experiment with the exception of session 4, indicating that the stable group may have practiced the strategy of task shedding. This finding shows that at moderate levels of sleep deprivation, individuals who were able to sustain performance under fatigue may
utilize compensatory efforts that include focus on the primary task at the expense of less critical tasks.

**ACRA-Rapid Decision Making**

The Rapid Decision Making test assesses the ability to make decisions regarding the selection of enemy targets within a constrained time limit. Unlike the attack combat scenario, measures of missed targets (lapses in attention) and reaction time variability are collected with this test as well as accuracy. A mixed-model ANOVA was performed on the Rapid Decision Making task metrics of percent correct, reaction time variability, and the number of misses. Only the percent correct metric was subject to significant fatigue effects, $F(5,96) = 3.29, p < .01$, with session 6 ($M = 91.18, SD = 2.45$) exhibiting lower scores than session 2 ($M = 96.41, SD = 2.75$) and session 5 ($M = 96.06, SD = 6.42$). This finding supports hypothesis H3. Though reaction time variability and misses exhibited increases during session 6, these effects were not significant. Hypothesis H4 stated that increases in reaction time variability and number of misses would occur prior to significant decreases in performance. Though this hypothesis was not supported statistically, a trend in increases did occur at session 3 and 4 for reaction time variability and at session 4 for the number of misses. The results for the Rapid Decision Making test metrics are presented in Figures 12, 13, and 14.
Figure 12. Rapid Decision Making percent correct as a function of continued wakefulness.

Figure 13. Rapid Decision Making reaction time variability as a function of continued wakefulness.

Figure 14. Rapid Decision Making number of misses as a function of continued wakefulness.
Individual differences were also investigated for the Rapid Decision Making task. In order to determine whether a similar categorization of “stable” versus “fatigue Vulnerable” groups also resulted for the Rapid Decision Making test and also whether this dichotomy in performance occurs for the same individuals, a stable by fatigue vulnerable matrix was generated for both the number of enemy kills and the Rapid Decision Making metrics. Difference scores were first generated for each individual from session 1 to session 6. Individuals who either did not change in their performance or whose performance increased were categorized as stable and those who decreased in performance were categorized as fatigue vulnerable. Table 2 lists the difference scores (session 6 - session 1) as well as the associated classification for each Rapid Decision Making metric.

Table 2

Rapid Decision Making classification as a function of differences in performance from session 1 to session 6.

<table>
<thead>
<tr>
<th>Percent Correct Classification</th>
<th>Reaction Time Variability Classification</th>
<th>Number of Misses Classification</th>
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</thead>
<tbody>
<tr>
<td>S1</td>
<td>S6</td>
<td>S6-S1</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>93.8</td>
<td>78.1</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>96.9</td>
<td>81.3</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>100</td>
<td>85.9</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>96.9</td>
<td>85.9</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>98.4</td>
<td>89.1</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
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<td>90.6</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>92.2</td>
<td>84.4</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>93.8</td>
<td>87.5</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
<td>100</td>
<td>96.9</td>
</tr>
<tr>
<td>Fatigue Vul.</td>
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<td>96.9</td>
</tr>
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<td>Stable</td>
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<td>95.3</td>
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<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Stable</td>
<td>93.8</td>
<td>95.3</td>
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<td>Stable</td>
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<tr>
<td>Stable</td>
<td>93.8</td>
<td>98.4</td>
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</table>

These classifications were then compared to the classification of the number of enemy kills for the combat simulation. The matrices in Tables 3, 4, and 5 display the similarities between these classifications. For the Rapid Decision Making percent correct metric,
seven participants were categorized as stable where performance either remained the same or improved. Five out of seven of these participants were also categorized as stable for the number of enemy kills metric. Ten individuals were categorized as fatigue vulnerable, seven of which had the same categorization for the number of enemy kills attack combat metric.

Table 3

*Enemy kills and Rapid Decision Making percent correct group categorization.*

<table>
<thead>
<tr>
<th>Number of Enemy Kills</th>
<th>Rapid Decision Making Percent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatigue Stable</td>
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<tr>
<td>Stable</td>
<td>5</td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
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<tr>
<td>Vulnerable</td>
<td></td>
</tr>
</tbody>
</table>

A similar break also occurred for the reaction time variability and the number of misses metrics. These matrices are also shown in Tables 4 and 5.

Table 4

*Enemy kills and Rapid Decision Making Reaction time variability group categorization.*

<table>
<thead>
<tr>
<th>Number of Enemy Kills</th>
<th>Rapid Decision Making RT Variability</th>
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<tbody>
<tr>
<td></td>
<td>Fatigue Stable</td>
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<tr>
<td>Stable</td>
<td>5</td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
</tr>
<tr>
<td>Vulnerable</td>
<td></td>
</tr>
</tbody>
</table>
Table 5

*Enemy kills and Rapid Decision Making number of misses group categorization.*

<table>
<thead>
<tr>
<th>Number of Enemy Kills</th>
<th>Rapid Decision Making</th>
<th>number of misses group categorization.</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Stable</td>
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<td></td>
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Because the same individuals were not categorized in the same way for both the combat simulation task and the Rapid Decision Making task, efforts to predict individual differences must be analyzed separately.

First, it is important to determine if performance on the Rapid Decision Making task was differentiated by stable vs. fatigue vulnerable individuals as categorized by the combat simulation task. The percentage of correct responses demonstrated group differences very similar to those of the enemy kills combat simulation metric. A main effect for session for percent correct was found, $F(5, 90) = 3.41, p < .01, \eta^2 = .21$, as well as for group, $F(1, 90) = 6.31, p < .05, \eta^2 = .20$, with the fatigue vulnerable group performing significantly worse than the stable group. Post-hoc analysis with Bonferroni corrections revealed significant differences between session 2 ($M = 96.39, SD = 2.45$) and session 6 ($M = 91.42, SD = 6.42$) as well as between session 5 ($M = 96.01, SD = 2.75$) and session 6. In addition, a significant interaction between session and group resulted, $F(5, 90) = 2.60, p < .05, \eta^2 = .12$. Figure 15 shows this interaction effect. Post-hoc independent sampled t-tests revealed a significant difference between groups at session 6, $t(15) = 3.36, p < .01$. 
Figure 15. Rapid Decision Making percent correct as a function of continued wakefulness: stable vs. fatigue vulnerable groups as categorized by the combat simulation.

Rapid Decision Making reaction time variability was not found to be significantly different between groups or between sessions. In addition, no interaction resulted, though trends revealed an increase in variability at session 3, 4 and 6 for the fatigue vulnerable group only (See Figure 16).

Figure 16. Rapid Decision Making reaction time variability as a function of continued wakefulness: stable vs. fatigue vulnerable groups as categorized by the combat simulation.
The number of misses on the Rapid Decision Making test revealed a marginal effect for group, $F(1, 45) = 4.02, p = .051$, with the fatigue vulnerable group performing significantly worse than the stable group and a main effect for session, $F(5, 22) = 2.72, p < .05, \eta^2 = .24$, with Bonferroni corrections revealing no significant differences between sessions. The interaction was not significant. Given the apparent differences illustrated in Figure 17, independent samples t-test for Rapid Decision Making number of misses was conducted. There was a significant difference between groups at session 6, $t(12) = -2.55, p < .01$. While a significant difference at session 6 was found for the number of misses, this effect was not strong enough to be identified by a significant interaction in the overall analysis suggesting unreliability.

![Figure 17. Rapid Decision Making number of misses as a function of continued wakefulness: stable vs. fatigue vulnerable groups as categorized by the combat simulation.](image)

The above results demonstrate that the majority of individuals who were classified as fatigue vulnerable using the combat simulation task were also classified as fatigue vulnerable using the Rapid Decision Making task. In addition, differences in performance on the Rapid Decision Making task percent correct metric were shown to
vary as a function of fatigue when stable vs. fatigue vulnerable individuals were classified by the combat simulation task. This finding gives promise that synthetic cognitive tests can predict performance on real-world tasks.

**ACRA-Tower of Hanoi**

The Tower of Hanoi test did not demonstrate sensitivity to fatigue stress. The overall performance trends for the Tower of Hanoi metrics of solution time, number of moves, and number of legality errors are shown in Figure 18, 19, and 20. Two data points were removed from these analyses due to extensive completion times (40 seconds and 180 seconds). Thus, H5 was not supported.

*Figure 18. Tower of Hanoi time to completion as a function of continued wakefulness.*

*Figure 19. Tower of Hanoi number of moves as a function of continued wakefulness.*
Several explanations are possible for the test’s lack of sensitivity. First, the Tower of Hanoi is a traditional problem solving task that has marked practice effects. The participants in the present experiment were fully trained on the 3-disk trials prior to sleep deprivation (4 and 5-disk conditions were also tested and data revealed practice effects or improved performance over testing sessions). All but one participant was able to perform the 3-disk Tower of Hanoi in the optimal number of moves (7 moves) during the first data collection period. It can be argued that having learned the optimal method for solving the task that the optimal sequence of moves becomes automated. Thus, the task is predictable making it cognitively different than the unpredictable, response selection task of target shooting in a changing environment.

Using the same criterion for dichotomizing individuals as either stable or fatigue vulnerable, a natural split in all metrics for the Tower of Hanoi did not occur. This is mostly due to the insensitivity of the task to fatigue stress. The solution time metric did produce a similar spilt to the combat simulation and the Rapid Decision Making task (recall that classification is based on difference scores where increases or no change from
session 1 to session 6 would result in a stable classification and a decrease in performance would result in a fatigue vulnerable classification), but the categorization was also different than the enemy kills attack combat metric. These matrices are shown in Table 6 (all participant data is included in classification).

Table 6

*Stable vs. fatigue vulnerable classification comparisons between the number of enemy kills and the Tower of Hanoi performance metrics.*

<table>
<thead>
<tr>
<th>Number of Enemy Kills</th>
<th>Solution Time</th>
<th>Fatigue</th>
<th>Stable</th>
<th>Fatigue</th>
<th>Vulnerable</th>
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These matrices are shown in Table 6 (all participant data is included in classification).

Table 6

*Stable vs. fatigue vulnerable classification comparisons between the number of enemy kills and the Tower of Hanoi performance metrics.*

<table>
<thead>
<tr>
<th>Number of Enemy Kills</th>
<th>Solution Time</th>
<th>Fatigue</th>
<th>Stable</th>
<th>Fatigue</th>
<th>Vulnerable</th>
<th>Stable</th>
<th>Fatigue</th>
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Next, it was also important to determine if performance on the Tower of Hanoi task was differentiated by stable vs. fatigue vulnerable individuals as categorized by the combat simulation task. None of the Tower of Hanoi metrics differed significantly by group or session.

Past research has shown that fatigue does lead to an increase in perseverative errors with problem solving solution time increasing due to the increase in such errors (Van der Linden, Frese, & Meiijman, 2003). However, such perseverative errors were found as a function of time-on-task, not sleep deprivation. Thus, decrements in problem solving solution time may be a function of vigilance as opposed to fatigue.

![Figure 21. Tower of Hanoi number of moves as classified by the combat simulation: stable vs. fatigue vulnerable groups.](image)
In conclusion, the lack of association between the Tower of Hanoi and the combat simulation task could be due to the test’s lack of sensitivity when trained to optimal performance, the lack of appropriate cognitive mapping between the tasks, issues related to Type II errors, or that a well-practiced task with consistent mapping is not vulnerable to the effects of fatigue.

**Participant State Variables**

Another purpose of the present study was to investigate the ability of stress appraisals and affect to explain differences in performance as a function of fatigue. With
the identification of a stable vs. fatigue vulnerable split for both the combat simulation and the Rapid Decision Making test, the present research investigated the ability of stress appraisals and affect to explain such dichotomies in performance. In addition, new categorization of stable vs. fatigue vulnerable was generated to distinguish between individuals whose performance remained the same or improved on both the combat simulation and the Rapid Decision Making test and those whose performance degraded on both tasks. It is assumed that individuals whose performance degraded on both tasks may be vulnerable to fatigue effects regardless of context or assessment type. Thus, any variable capable of identifying those who are vulnerable to fatigue on several tasks may provide information regarding a trait characteristic as opposed to a state factor that might temporarily affect performance. First, an investigation of the ability of stress appraisals and affect to explain performance dichotomies for the combat simulation and the Rapid Decision Making test individually was undertaken followed by an assessment of their ability to explain performance dichotomies across both tasks. Factors that explain performance differences on the individual tasks are considered state factors that affect performance in real-time as the appraisal or emotion occurs. Factors that explain performance dichotomies over both tasks are considered either stable characteristics or peripheral consequences of personality differences that may explain individual differences in fatigue vulnerability.

**Stress Appraisals**

The analyses of stress appraisals consisted of data from 16 participants, due to an additional outlier. Of these 16 participants, only 3 met the conceptual threat classification at baseline prior to the Rapid Decision Making task and only 2 met the conceptual threat
classification prior to the combat simulation. It was preferred to use the conceptual split for the current study to aid in the interpretation of the data (ratios greater than 1 indicate threat, while ratios less than one indicate challenge). A median split was also generated to compare both methods of categorization to data from other samples. As categorized by a median split (median = .78) prior to the Rapid Decision Making task, challenged individuals for the present sample had a mean of 0.48, and a standard deviation of 0.26. Threatened individuals had a mean of 0.99 and a standard deviation of 0.16. The median split prior to the combat simulation was similar (median = .79) with a mean of 0.92 for threatened participants ($SD = 0.10$) and a mean of 0.51 for challenged individuals ($SD = 0.16$). Employing the same instrument, Schneider (1997) found an even conceptual split with challenged individuals ($n = 26$) having a mean of 0.74 ($SD = 0.79$) and threatened individuals ($n = 26$) having a mean of 1.05 ($SD = 0.81$). These differences become even more pronounced when a stressor is introduced (startle) with challenged ($n = 11$) individuals resulting in a mean of 0.33 ($SD = 0.14$) and threatened individuals resulting in a mean of 1.71 ($SD = 0.95$).

Because the current data 1) did not produce an even split conceptually, and 2) produced a median split that is difficult to interpret with all means meeting the description of a challenged mindset (available resources exceeding task demands), the present study examined hypotheses related to stress appraisals as a continuous factor. However, analyzing a categorical variable as a continuum no longer allows for the present results to be compared to findings in past literature. The association of stress appraisals and performance was identified with data that categorized people as threatened or challenged and did not draw conclusions based in increases or decreases in stress.
appraisals. However, a recent study by Blascovich, Seery, Mugridge, Norris, and Weisbuch (2004) demonstrated that individual stress appraisals analyzed by a physiological continuum also showed the ability to predict differences in performance. Thus, the following results are to be interpreted with caution.

Research has traditionally shown that threat appraisals are associated with poor performance (Schneider, 2008). Bivariate correlations were computed at each session to test for relationships between stress appraisals and performance on the combat simulation. At session 3, stress appraisals were significantly related to friendly fire, $r = .65, p < .05$, indicating that higher threat levels are associated with more friendly fire at a moderate level of fatigue. At session 5, stress appraisals were significantly related to enemy kills, $r = .55, p < .05$, indicating an association between higher threat levels and more enemy kills. Thus, under a high level of fatigue, threat enhanced performance on the primary dependent measure.

It was hypothesized that the fatigue vulnerable group, as categorized by the number of enemy kills, would show increasing levels of threat as fatigue increased. This is because fatigue should cause one to appraise the situation as more threatening due to the decrease in resources available to the individual. This hypothesis was not supported (See Figure 24).
Figure 24. Stress appraisal ratios as classified by the combat simulation: stable vs. fatigue vulnerable groups.

A main effect for group and for session on stress appraisals was not found. In addition, an interaction was only marginal with no clear indication of the differences in trends between the two groups, $F(5, 65) = 2.34, p = .051$, failing to support H7. An important observation of this finding is that neither group ever reached the conceptual “threat” appraisal throughout the entire experiment, contrary to hypothesis H6. This study introduces the possibility that fatigue may not serve as a personal threat factor and may influence performance more objectively as opposed to subjectively. Because stress appraisals are dependent on subjective evaluations of the situation, in order for the stressor to be evaluated accurately, individuals would have to be accurate assessors of fatigue. Researchers have shown that this is not the case when it comes to fatigue stress. In fact, we are very poor estimators of our ability when fatigued (Van Dongen, Maislin, Mullinton, & Dinges, 2003). Another explanation is that threat may actually function to facilitate performance as illustrated in Figure 3 though anxiety. This will be explained in more detail below.
Affect

Positive affect revealed both a main effect for group, \( F(1, 22) = 6.35, p < .05, \eta^2 = .22 \), with the stable group reporting more positive affect than the fatigue vulnerable group and a main effect for session, \( F(5, 68) = 4.87, p = .001, \eta^2 = .30 \), with session 1 (\( M = 52.47, SD = 8.55 \)) exhibiting more positive affect as compared to session 2 (\( M = 47.72, SD = 7.47 \)) and session 6 (\( M = 44.15, SD = 3.31 \)), and session 5 (\( M = 48.90, SD = 7.97 \)) exhibiting more positive affect as compared to session 6. These were Bonferroni-corrected significant differences. Thus H8 stating that positive affect would significantly decrease as a function of fatigue was supported. Positive affect results are shown in Figure 25.

![Figure 25](image)

**Figure 25.** Positive affect as classified by the combat simulation by group: stable vs. fatigue vulnerable groups.

Negative affect did not show any significant effects – though the stable group showed a mean score substantially higher than the general population at session 6 (see Figure 26). Negative affect trends revealed an interesting pattern where scores essentially did not change for the fatigue vulnerable group, but appear to fluctuate and increase for the stable group, particularly at the time when the performance dichotomy emerges.
However, these results are not significant. Consequently an exploratory examination of particular negative affects was undertaken. In order to explore the possibility of negative affect factors operating differentially, a mixed-model ANOVA was performed separately on the 3 negative affect scales of anxiety, depression, and hostility.

Figure 26. Negative affect as categorized by the combat simulation by group: stable vs. fatigue vulnerable groups.

The only negative affect factor to show an effect for group or session is that of anxiety. Anxiety revealed a significant group by session interaction, $F(5, 56) = 2.64, p < .05$, $\eta^2 = .13$ (see Figure 27). Post-hoc independent samples t-tests revealed a marginal difference between groups at session 6, $t(15) = 1.90, p = .077$. It could be argued that such post-hoc t-test comparisons should be treated as a one-tailed test due to the previously identified direction of the results. This would generate a significant difference.
Figure 27. Anxiety as classified by the combat simulation by group: stable vs. fatigue vulnerable groups.

However, a single t-test was performed on the difference scores from session 1 and session 6 (recall that this is how the fatigue vulnerable and stable group was generated). Results revealed a significant difference between groups with the stable group exhibiting significantly greater increases in anxiety levels from session 1 to session 6 as compared to those who were fatigue vulnerable, $t(15) = 2.34, p < .05$ (stable $M = 10.88, SD = 13.83$; fatigue vulnerable $M = -10.89, SD = 22.77$). Further backing up this finding is a significant positive correlation, $r = .51, p < .05$, between differences in anxiety scores (session 6 – session 1) and differences in the number of enemy kills (session 6 – session 1). Thus, the greater increase in anxiety, the greater increase in the number of enemy kills. This finding supports the Arousal-Fatigue Model, but fails to support the adapted the Adapted Stress Appraisal Model. The Arousal-Fatigue Model illustrates that increases in anxiety would be associated with performance sustainment or improvement under sleep deprivation, as hypothesized (H10b). However, as assessed prior to the combat simulation, depression was not found to be associated with decreases in performance.
Table 7 shows the number of individuals who either increased, did not change, or decreased in anxiety levels from session 1 to session 6 for both the stable and the fatigue vulnerable groups. It can be seen from this table that increases in anxiety are characteristic mainly for those categorized as “stable.” It is important to use caution when interpreting these results. The groups under investigation (stable vs. fatigue vulnerable) did not differ in their levels of anxiety; rather, they differed in the direction and degree of change in anxiety levels. Thus, anxiety would have to be monitored in real time in order to detect the signature trend of either stable or fatigue vulnerable group behavior.

Table 7

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<tr>
<th>Anxiety change scores as a function of fatigue for both the stable and fatigue vulnerable groups.</th>
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<td>Change in anxiety scores from session 1 to session 6</td>
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<tr>
<td>Stable</td>
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<td>Fatigue Vulnerable</td>
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Explaining Fatigue Vulnerability for the Rapid Decision Making Test

Because the same stress appraisal and affect variables were assessed prior to the ACRA tests as were tested prior to the Attack Combat Scenario, the opportunity was available to test for the same pattern of results. Recall that the Rapid Decision Making test revealed similar performance changes as did the number of enemy kills metric of the combat simulation test. Also recall that the only affect variable to demonstrate sensitivity to fatigue vulnerability was anxiety. Therefore, the result pattern of interest here was that of performance differences on the Rapid Decision Making test (The Tower of Hanoi was
not investigated due to the lack on demonstrated sensitivity to fatigue stress) as a function of anxiety.

Bivariate correlations revealed a significant relationship between stress appraisals and Rapid Decision Making reaction time variability, $r = .49$, $p < .05$, and number of misses, $r = .49$, $p < .05$, at session 4. In addition, though stress appraisals reached the conceptual threat level at session 6 for all participants on average ($M = 1.41$, $SD = 1.54$), the mixed-model ANOVA did not reveal significant changes across session, failing to support the hypothesis that stress appraisals would increase as a function of continued wakefullness (H6). In addition, an effect for group was not found failing to support the hypothesis that higher stress appraisals would be associated with fatigue vulnerability (H7). A main effect for session was found for positive affect or all three dependent variables, $F(5, 69) = 4.59$, $p = .001$, $\eta^2 = .23$ percent correct, $F(5, 69) = 4.91$, $p = .001$, $\eta^2 = .26$ reaction time variability, and, $F(5, 69) = 5.00$, $p = .001$, $\eta^2 = .26$ number of misses (See Figures 28, 29, and 30). These findings support H8.

Figure 28. Positive affect as classified by the Rapid Decision Making percent correct metric: stable vs. fatigue vulnerable groups.
Figure 29. Positive affect as classified by the Rapid Decision Making reaction time variability metric: stable vs. fatigue vulnerable groups.

Figure 30. Positive affect as classified by the Rapid Decision Making number of misses metric: stable vs. fatigue vulnerable groups.

Negative affect revealed a significant interaction of session and group on reaction time variability, $F(5, 62) = 2.80$, $p < .05$, $\eta^2 = .10$. These results are plotted in Figure 31. Independent sampled t-tests revealed only marginal differences at session 6, $t(15) = 2.04$, $p = .057$, suggesting that this finding may be unreliable. However, these results also demonstrate greater fluctuation for the stable group vs. the fatigue vulnerable group.
Figure 31. Negative affect as classified by Rapid Decision Making reaction time variability: stable vs. fatigue vulnerable groups.

A main effect for session on anxiety for the Rapid Decision Making percent correct metric was found, $F(5, 57) = 2.54, p < .05, \eta^2 = .12$, and the reaction time variability metric, $F(5, 57) = 2.96, p < .05, \eta^2 = .14$, with Bonferroni corrected post-hoc comparisons revealing no significant differences between sessions, failing to support hypotheses (H10a and H10b) related to the effect of anxiety on performance.

A main effect for group on depression scores for the Rapid Decision Making number of misses metric, $F(1, 24) = 5.20, p < .05, \eta^2 = .21$, with the fatigue vulnerable group exhibiting higher depression scores throughout the sleep deprivation period as compared to the stable group (see Figure 32). This finding supports both the Adapted Stress Appraisal Model and the Arousal-Fatigue Model, which state that depression would exhibit associations with decreases in performance. The interaction that was found for the combat simulation between anxiety and performance was not found for the synthetic task of Rapid Decision Making. Instead, stable vs. fatigue vulnerable individuals differed more in their levels of depression. Thus, it can be concluded that
negative affect not only influences performance differentially, but that it is context specific.

Figure 32. Depression as categorized by Rapid Decision Making number of misses: stable vs. fatigue vulnerable groups.

Explaining Fatigue Vulnerability using Classification based on Multiple Criteria

The next objective of this study was to place a stricter criterion on the classification of stable and fatigue vulnerable by only including individuals who either remained stable throughout both the combat simulation task (number of enemy kills metric) and all three Rapid Decision Making metrics and those who decreased performance for all four factors. In order to determine if stress appraisals and affect could explain individual differences in the context of this stricter criteria, several mixed-model ANOVAs were performed on these factors comparing stable (N = 4; performance either remained the same or increased from session 1 to session 6 for the number of enemy kills metric and all three metrics of the Rapid Decision Making metrics) and fatigue vulnerable (N = 6; performance degraded from session 1 to session 6 for the number of enemy kills and all Rapid Decision Making metrics) individuals. It is important to note that stress appraisal and affect assessments were made prior to both the
attack combat task and the Rapid Decision Making task. Thus, analyses were conducted separately for each task though the categorization remained the same.

**Stress Appraisals**

Stress appraisals as assessed prior to the Rapid Decision Making task and the combat simulation did not reveal any significant differences between stable and fatigue vulnerable individuals. These results is shown below in Figures 33 (a) and (b).

*Figure 33 (a) and (b).* Stress appraisals prior to both the (a) combat simulation and (b) the Rapid Decision Making test: stable vs. fatigue vulnerable groups.

It can be seen from these results that the fatigue vulnerable group exhibited similar trends in stress appraisals for both the combat simulation and the Rapid Decision Making task. In contrast, the stable group demonstrated task sensitivity with fluctuating stress appraisals prior to the synthetic task and increasing stress appraisals prior to the combat simulation task.

**Affect**

A main effect for session was found on positive affect prior to both the Rapid Decision Making test, $F(5, 38) = 5.11, p = .001$, and the combat simulation, $F(5, 36) = 3.04, p < .05$. In addition a significant group effect was found prior to the combat
simulation, $F(1, 12) = 4.72, p = .05$, with stable individuals reporting more positive affect ($M = 51.15, SD = 8.59$) than fatigue vulnerable individuals ($M = 45.80, SD = 4.98$).

A session by group interaction was found for negative affect prior to the Rapid Decision Making task only, $F(5, 35) = 2.66, p < .05$. For the purposes of comparison, Figures 34 (a) and (b) show the negative affect trends prior to both the Rapid Decision Making task and the combat simulation task.

Figure 34 (a) and (b): Negative affect scores prior to both the (a) combat simulation and (b) the Rapid Decision Making test: stable vs. fatigue vulnerable groups.

It can be seen from Figure 35 that regardless of significance, the stable group had more fluctuation in negative affect scores during both tasks, while the fatigue vulnerable group remained relatively stable.

Group or session differences were not found for anxiety prior to the combat simulation task. Prior to the Rapid Decision Making task, a main effect for session was found, $F(5, 31) = 3.74, p < .01$, with Bonferroni corrected comparisons revealing no significant differences as expected with a small sample size. Recall that a main effect for session was also found when comparing between groups as categorized only by the Rapid Decision Making task. In addition, a marginal interaction was found, $F(5, 31) = 2.45, p = .056$. Figures 35 (a) and (b) show anxiety trends prior to both tasks.
Figure 35 (a) and (b). Anxiety scores prior to both the (a) combat simulation and (b) the Rapid Decision Making test: stable vs. fatigue vulnerable groups.

Though significant differences were not found prior to the combat simulation, anxiety trends are very similar to the trends that emerged when comparing anxiety trends between stable and fatigue vulnerable individuals as categorized only by the combat simulation enemy kills metric (Figure 27). Though difference scores from session 1 to session 6 did not reveal differences, the proportion of change for both groups is identical. However, none of the cross-stable individuals exhibited a decrease in anxiety. Table 8 shows these proportions.

Table 8

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<td>Cross-Fatigue Vulnerable</td>
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Depression did not result in any significant differences prior to the Rapid Decision Making test, but did result in a significant main effect for session prior to the combat simulation, $F(5, 48) = 2.69, p < .05$, with significant Bonferroni corrected Post-hoc comparisons revealing significant differences between Session 5 ($M = 47.00, SD = 0.00$) and Session 6 ($M = 71.00, SD = 27.71$). For purposes of comparison, Figures 36 (a) and (b) show the depression trends prior to both tasks.

Figure 36 (a) and (b). Depression scores prior to both the (a) combat simulation and (b) the Rapid Decision Making test: stable vs. fatigue vulnerable groups.

Summary

In general, the current study revealed individual differences in performance as a function of continued wakefulness. Specifically, approximately half of the participants exhibited the ability to sustain performance on a high-fidelity attack combat simulation, while the other half decreased in performance from session 1 to session 6. In an effort to explain the identified dichotomy in performance it was found that synthetic task performance, for the metric of accuracy, was successful in identifying such individual differences. It was also found that a task with consistent stimulus-response mapping and
predictability was a poor candidate for the prediction of a high-fidelity task that represents a changing environment.

It was found that the ability of subject state variables to explain individual differences in fatigue vulnerability is dependent on the type of performance task. When assessed prior to a high-fidelity combat task, the Arousal Fatigue Model presented in Figure 3 appears to most appropriately fit the performance data. In general, it appears that negative affect and stress appraisals fluctuate more for stable individuals, stable individuals exhibit more positive affect as compared to fatigue vulnerable individuals, and that anxiety may be predictive of the ability to sustain performance under fatigue. Specifically, it was found that the stable group significantly increased anxiety levels from session 1 to session 6, whereas the fatigue vulnerable group significantly decreased in anxiety from session 1 to session 6.

In addition, it appears that individuals classified as stable by a more strict context-independent criteria revealed more fluctuation in negative affect scores and stress appraisals as a function of fatigue, suggesting that those individuals less vulnerable to fatigue may be more sensitive to stability properties and able to adjust to the changes in task demands that occur as a function of sleep deprivation.
V. DISCUSSION

This study demonstrated that in a group of seventeen active duty soldiers, performance on an attack combat simulation significantly degraded at session 6 (after 30 hours of sleep deprivation) for the primary dependent variable of enemy kills. In addition, individual differences were identified as approximately half of the participants maintained performance throughout the sleep deprivation period (stable performance) on the primary dependent variable, while the other participants degraded in performance (fatigue vulnerable). It is also important to note that the stable group had fewer mine kills throughout the experiment with the exception of session 4. This finding suggests that at approximately 18 h of sleep deprivation, individuals who were able to sustain performance under fatigue may utilize compensatory efforts that included focusing on the primary task at the expense of less critical tasks. The main objective of this study was to assess for the ability of synthetic (micro-level) performance metrics as well as participant state factors to identify individuals who are more vulnerable to fatigue.

Synthetic Task Performance

The first group of factors that were tested included more micro-level performance metrics that were hypothesized to either exhibit early or synchronous changes in performance. These factors included accuracy, reaction time variability, and lapses in attention. The results showed that performance metrics on a Rapid Decision Making test showed the ability to demonstrate performance changes synchronous to those of the attack combat scenario. While changes in variability and lapses of attention were hypothesized to show even earlier differences between stable individuals and fatigue vulnerable individuals, significant differences were not found. However, a trend did
occur at session 3, 4, and 6. One possible explanation for this lack of statistical significance is that variability changes or lapses in attention may predict future decrements in performance, but in a subtle manner. Perhaps the variability metric is a signature of future significant, qualitative change rather than a separate cognitive metric. Increases in variability only occurred for the fatigue vulnerable group. For example, Gaustello (1995) explained that reaction time variability increases just before average reaction time makes a significant change and just after. This would mean that variability is more of an instability identifier where significant changes are only seen at the “phase change” point of performance or the point at which performance changes significantly. In the current data, session 5 occurred mostly during a circadian peak, disallowing for the continued trend of increasing variability. Therefore, even though the current effort did not identify early detection of significant performance changes through micro-level performance metrics such as increases in variability and lapses in attention or misses, these results call for future assessments of subtle changes and the diagnosticity of such subtle changes in predicting future, significant and qualitative changes in performance. If future studies reveal patterns such as those found in the present study, more sensitive indicators of variability changes need to be developed and tested.

As mentioned in the results section, several explanations are possible for the Tower of Hanoi’s lack of sensitivity. First, the Tower of Hanoi is a traditional problem solving task that has marked practice effects. The participants in the present experiment were fully trained on the 3-disk trials prior to sleep deprivation. All but one participant was able to perform the 3-disk Tower of Hanoi in the optimal number of moves (7 moves) during the first data collection period. It can be argued that having learned the
optimal method for solving the task, the optimal sequence of moves becomes automated. Thus, the task is predictable making it cognitively different than the unpredictable, response selection task of target shooting in a changing environment.

Another possible explanation for the lack of sensitivity of the Tower of Hanoi to sleep deprivation effects is the lack of neuronal control explanation offered by Carver and Scheier (1991). Because practice effects were found with the 4-disk and 5-disk version of the Tower of Hanoi, the ability of this test to differentiate fatigue vulnerable individuals from performance stable individuals was limited to the highly practiced and possibly automated 3-disk Tower of Hanoi Task. Thus, regardless of whether higher order cognitive processes were degraded due to fatigue (recall that 25% performance degradations were found after 24 h of sleep loss Babkoff et al., 1985; Thorne, Genser, Singe, & Hegge, 1983), lower-order process are still capable of being carried out. However, in the context of the attack-combat simulation where the task set-up and enemy configurations are changed from trial to trial, such automaticity is impossible to develop.

**Stress Appraisals**

It is important to note that past research tested stress appraisals as a dichotomous variable and that comparison to the present results should be done with caution. In addition, recall that the majority of participants met the conceptual challenged categorization prior to cognitive testing. It was hypothesized that threat appraisals would increase (either challenged individuals would switch to a threatened categorization or threatened individuals would remain threatened) as fatigue increased due to the loss of resources available to perform the tasks. The results of the present study indicate that though in the correct direction, these changes were not significant. One reason for this
lack of association is the finding that individuals are poor estimators of ability under fatigue (Van Dongen, Maislin, Mullinton, & Dinges, 2003). Since the Stress Appraisal Scale is a subjective assessment of stress and available resources, the association between these variables may be confounded by the belief that ability has not deteriorated. Another explanation is that fatigue operates differently than other stressors. While combat stress, evaluation stress, or even workload stress may lead to threat for some individuals, fatigue actually leads to decreased motivation, greater distraction, and a detachment from the task. Thus, while available resources are depleting, the motivation to perform may also be decreasing causing the stress appraisal ratio to remain unchanged.

Affect

It was hypothesized that a significant negative linear trend in negative affect would result as a function of fatigue. Contrary to past literature (Lieberman, et al., 2005; Thorne, et al., 1983), this was not found though average scores slightly increased. This lack of significant finding may be due to several factors. One possibility is that ~30 h of sleep deprivation is not enough to show pronounced changes in affect. In addition, negative affect is not measured in the same way across different studies. Typical measures included the Positive and Negative Adjective Scale (PANAS; Watson, Clark, & Tellegen, 1988), the Profile of Mood States (POMS; McNair, Lorr, & Droppleman, 1981), and the selection of the current study – the MAACL-R. With the recent findings that negative affect operates differentially to influence performance depending on the components that define negative affect, the selection of affect assessment becomes critical.
Hypotheses related to negative affect and group differences were made more specific regarding anxiety, hostility, and depression. The construction of these hypotheses was based on two possible scenarios. The first scenario followed general performance under stress literature and posited that hostility would sustain performance while anxiety would lead to degraded performance. Figure 2 illustrates these associations. This theoretical affect-performance relationship was not demonstrated under the current sleep deprivation profile.

The other set of hypotheses posited that anxiety may interact with fatigue as to either sustain or even increase performance by narrowing attention on the primary task. Such hypotheses are based on the inverted-U performance arousal curve that places different stressors as either performance inhibiting or performance enhancing (Matthews, Davies, Westermann, & Stammers, 2000). The present study found that those individuals who were categorized as stable exhibited significantly higher increases in anxiety from baseline to ~30 h of sleep deprivation when compared to fatigue vulnerable individuals. This is an important empirical finding as anxiety is usually associated with task disengagement (Matthews, Davies, Westermann, & Stammers, 2000). In addition, it was found that stable individuals showed more positive affect and task shedding at moderate levels of fatigue. Figure 37 highlights the links in Figure 3 that were found to be supported by the present data.
This anxiety-fatigue interaction on high-fidelity task performance may have a theoretical explanation; however, sound empirical validation is lacking in the literature. Thus, future research is warranted in this area. First, it was necessary to see if this relationship also occurs in a low-fidelity, synthetic task context.

Negative affect and group differences were also tested for the Rapid Decision Making Test. These results showed that neither hostility nor anxiety differed between those who were categorized as stable or fatigue vulnerable (anxiety increased overall across sessions). However, a main effect for group was found with depression and the number of attention lapses. Therefore, the present study not only showed a differential effect of negative affect and performance, but the task itself may interact with this association. The attack combat simulation was a realistic set-up with life-like battlefield noise and actual terrain mapping. Therefore, the participants were engaged in a stressful,
high-fidelity simulated task. The Rapid Decision Making task, on the other hand, only cognitively symbolized the actions that one would have to make on the battlefield. This task was not only an easy task, but did not produce any stress other than the fatigue stress itself. This increase in anxiety for those individuals who were able to sustain performance over ~30 h of sleep deprivation during the high-fidelity attack combat task may explain why decrements in performance under fatigue may not be found during field studies or simulated operations (Ainsworth & Bishop, 1971). The main effect for group suggests that depression was debilitating regardless of the level of fatigue. This finding is consistent with Davis and Nolen-Hoeksema (2000) who found that depressed individuals tends to ruminate and have increased errors.

Can we Identify Fatigue Vulnerability?

The main objective of the current study was to investigate whether certain stress appraisal and affect variables could modulate the effects of fatigue on performance. The present study found that individuals who were capable of maintaining performance also exhibited an increase in levels of anxiety over the sleep deprivation period. This finding can be explained in the context of the inverted-U hypothesis, which claims that performance inhibiting stressors such as fatigue will lead to less arousal and poorer performance while performance facilitation will occur, in the context of low arousal, under additional stressors that increase arousal such as threat or anxiety (Matthews, Davies, Westerman, & Stammers, 2000). The question remains, however, of why anxiety increased only for some individuals and not for others.

Several possible relationships exist for individuals who increase in anxiety under increasing task demand during sleep deprivation. Perhaps individuals with a higher
baseline cortical activation also have the potential to maintain arousal during under-stimulated circumstances. Recall that higher baseline cortical activation was found to be related to less fatigue vulnerability (Caldwell et al, 2005; Killgore, et al, 2007). It was also found that individuals’ with higher resting heart rate variability are better emotional regulators than those with lower resting heart rate variability (Appelhans & Luecken, 2006). Finally, it is important to mention that baseline cortical activation, resting heart rate variability, and the ability to increase arousal during under-stimulated circumstances could all bare a significant relationship.

Neurotic extraverts (Blasgrove & Akehurst, 2001) as well as those with an external locus of control (Hill, Welch, & Godfrey, 1996; Verwey & Zaidel, 2000) were found to be demonstrate fatigue vulnerability. Goal achievement and conscientiousness have not been studied, though would also be excellent candidates for identifying those who can sustain performance under fatigue. The present study did not record personality or trait factors. However, it is suggested that personality factors are explored in the context of present findings in future studies. For example, those with an internal locus of control may be more capable of recognizing the need to increase arousal (anxiety) in order to compensate for the inhibiting effects of fatigue. This idea is consistent with Hanoch and Vitouch’s (2004) cue-utilization theory, which explains that stress introduces constraints on attention and behavior and functions to facilitate performance on primary tasks. They explain that stress allows individuals to focus attention and mobilize the body to function optimally during urgent problems. Preparing the body may involve an increase in anxiety or in cortisol in preparation for stressful events. Perhaps those characterized as internals are more in tune with their biological needs and can recognize
the need to stabilize under inhibiting events. However, Hockey (1983) warns that arousal is a far more complex process than originally conceived and that caution should be taken when making inferences regarding mental arousal and changes in bodily functions.

**Study Limitations**

The ability to carry out the current objectives within a military installation and with enlisted Army personnel was a great opportunity. These individuals just completed basic training and were highly motivated to perform well and to contribute to the purpose of the continued wakefulness study. The study was optimally designed to assess for the capability of a select test battery to predict performance on a high-fidelity task under sleep deprivation. The study was well organized by the Army Research Laboratory of Aberdeen, MD and included several components, some of which were not discussed in the present dissertation. While the design of this study well met the needs of the Army Research Laboratory, it also generated some disadvantages to the present study objectives.

The main limitation of the current study is that it did not allow for an assessment of the effects of circadian rhythms. All 18 subjects were tested over a six-hour period of time at which a circadian peak or a circadian trough may have occurred only for some participants. For example, session 5 (~24 h of sleep deprivation) began at 7:00 pm and did not end until 1:00 am. During this time, a circadian peak could have occurred, particularly between the hours of 7:00 pm and 9:00 pm. Thus, participants 1-9 may have improved performance due to such circadian effects (though it is unlikely that the peak would have occurred at the time of testing for all 9 participants) where the other participants should have been coming down from a circadian peak during testing. With
only 3 participants in each group, such circadian effects could not be appropriately tested. This is a large confound in the study and it is recommended that the same factors be studied in a more controlled study design.

A second major limitation of the study was the freedom of participants to consume caffeinated beverages during the study. Though group differences were assessed on the amount of caffeine that was consumed throughout the study in order to rule-out caffeine as a determining factor of individual differences, $t(15) = 1.19, p = .251$, it would have been optimal to completely control for the effects of caffeine on performance. However, allowing for the consumption of caffeine did eliminate the possibility of group differences being due to caffeine withdrawal.

An additional limitation was that physiological data was not collected as part of this particular effort. Thus, no physiological evidence of fatigue is present. While it is assumed that the participants are sleepy due to the sustained wakefulness profile, the ability to consume caffeinated beverages along with identified individual differences leaves some uncertainty as to whether these participants are actually fatigued. Ideally, electroencephalographic data is typically collected during sleep deprivation testing. In addition, no subjective evaluation of sleepiness was included.

*Implications for Military Research*

The present study suggests that self-regulation properties are operating for individuals who are able to sustain performance under fatigue. This is identified through increases in anxiety at times when demand is high as well as significant increases in anxiety after 30 h of sleep deprivation. Provided the military has the capability to monitor anxiety levels during sustained operations, individuals could be pulled from duty once
such compensatory efforts are no longer exhibited. For example, anxiety is indexed by increases in hear rate and cortisol level (Lerner et al, 2007). Provided real-time assessment of these factors is possible, compensatory efforts can be monitored. Finally, once a clear picture emerges of individual differences in performance under fatigue, predictors of stability can be implemented as a classification factors for personnel selection.


neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, 26, 117-126.


APPENDIX A

Volunteer Agreement Affidavit
**VOLUNTEER AGREEMENT AFFIDAVIT:**  
ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

| The proponent for this research is: | U.S. Army Research Laboratory  
Human Research and Engineering Directorate  
Aberdeen Proving Ground, MD 21005 |

| Authority: | Privacy Act of 1774, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 USC 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities] |

| Principal purpose: | To document voluntary participation in the Research program. |

| Routine Uses: | The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies. |

| Disclosure: | The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection. |

**Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects**

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of participating in this project (under the provisions of AR 40-38 and AR 70-25).

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<tr>
<th>Title of Research Project:</th>
<th>Modulation of selective attention mechanisms by psychophysiological stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Use Protocol Log #</td>
<td>ARL-20078-</td>
</tr>
</tbody>
</table>
| Principal Investigator:   | Robert O’Donnell  
NTI, Inc.  
5200 Springfield Street  
Dayton, OH 45431 |
| Phone: | 937-253-4110  
E-Mail: ODNova@aol.com |
Purpose of the Research

You are being asked to volunteer in a series of three experiments being conducted in succession. The first experiment will examine the sensitivity of the Army Cognitive Readiness Assessment (ACRA) Battery on cognitive processing when performing a variety of tasks. Information gathered from this study will be used in subsequent research endeavors and will be used to assess the impact of short-term stress on cognitive performance. The second study is designed to aid us in understanding how information provided by remote sensors (such as unmanned aerial vehicles) will help you navigate through and understand events happening in your environment. The third study is designed to examine your ability to perform shooting tasks under different levels of workload and while performing decision making tasks.

Procedures

If you agree to participate in this study, you will be asked to sign this Volunteer Agreement Affidavit. You will then complete a brief vision and hearing screening. We will be assessing your visual acuity, color vision, and hearing threshold. Next, you will complete a series of questionnaires. First, you will be given a list of adjectives (known as MAACL-R) and asked to check all the words that describe how you feel right now. Next, you will be asked to complete a cultural diversity and team behavior questionnaire followed by a demographics questionnaire. We would like to obtain your ASVAB score; however, this is your choice and you need not feel pressured to provide your score. There is a designated area provided at the bottom of this form if you wish to give permission for us to obtain your ASVAB score.

The first day of the study will be a training day. Testing will begin on day 2 in building 459 of the ARL and will continue for 48 hours without sleep. Transportation to and from the test site and your duty station will be provided by the ARL. On training day, you will be trained on the cognitive assessment battery (ACRA) and on a first person video game called Raven-Shield. You will also be shown the location of the facilities, the participant waiting room, designated smoking areas and the dining area. You will also be introduced to the experimenters, any of whom will be
glad to answer questions. At the end of the training you will be returned to your duty station.

The following day, you will be picked up at your duty station at 1800. Upon arrival, at the ARL, you will be fitted with a heart monitor, which consists of a strap worn comfortably around the chest and a wrist-watch type device. A plastic strip, similar to an ordinary BandAid will be placed at the back of your neck to monitor skin temperature. You will wear the chest strap, wrist watch, and temperature strip throughout the study. If at any time you feel discomfort from any of these devices, please inform the experimenter and the devices will be adjusted or removed if the discomfort persists.

One part of this study is assessing the ability of the ACRA to predict performance as you become fatigued. For purposes of testing and accountability, you will be divided into groups of three and you will remain with your group throughout the test period. You will begin by completing a series of questionnaires concerning what you’re feeling about your current workload, stress, and level of fatigue. The questionnaires should take less than 5 minutes to complete. You will then complete a 15 session of the ACRA, which will be administered to one individual at a time. During ACRA, we will use a camera to measure your eye movements. The eye is illuminated with infrared light, which is similar to visible light but has a longer "wavelength" and cannot be seen by the human eye. The amount of infrared light reaching your eye is only 20% of the maximum allowable exposure level as specified by the Department of Health Education and Welfare. In addition, we will shine a laser beam over the large artery in your neck (the carotid artery). The laser beam is low power and will shut off automatically if it is pointed anywhere except the target spot on your neck. This laser beam will not pose any physical harm to you.

When all three individuals in your group have completed the ACRA, your group will be escorted to the video game stations located in an adjacent building. At the beginning of each video game session, you will again complete the fatigue and stress questionnaires. Upon completion of the questionnaires, each member of your group will begin the video game simultaneously; however, you will be playing as an individual and not a team. The game play will last for 20 minutes and then you will receive a 5 minute break and begin another 20 minute game. You will be wearing headphones during the game over which you will hear the sounds inherent to the game (footsteps, gunfire, breathing sounds, etc). During one of the 20 minute game play periods you will hear only the game-generated sounds coming through the headphones. During the other 20 minute game play, in addition to the sounds produced by the game, you will hear the background noises of battle (artillery shelling, mortar fire, grenades, etc.) as projected from speakers in the room. The sounds will be loud, but will be maintained below the maximum safety levels and allowable daily levels determined by the OSHA and the U.S. Army Standard (DA PAM-40-501R with addenda). The order in which the battle noises and game noises are presented will vary. Sometimes you will play the 20 minute battlefield noise session first and sometimes the game noise session will be first. Following completion of the video game, you will once again complete the MAACL-R and a selection of the fatigue and workload questionnaires. Once you have completed the questionnaires, you will be escorted back to building 459 where you will be asked to perform a computer-based simulation referred to as G8.
You will then be escorted to the G8 Remote Sensor Study room. The purpose of this task is to evaluate the ability of soldiers to understand and use information provided from remote sensors. We will evaluate the effect of sleep deprivation on the effectiveness of the remote sensor information using two different cuing conditions. During the task, you will be sitting in front of a large screen. On the large screen you will navigate through an environment created using a first-person shooter computer game. You will navigate to six different waypoints using a paper map and digital map provided on a PDA-type display. At each waypoint you will be shown an image that simulates a view from an Unmanned Aerial Vehicle (UAV) and asked to locate your own position on the image. You will then be asked to identify another location on this same image. You will answer each question by moving the mouse to the appropriate location and clicking the mouse to designate the location on the image. After you have navigated to all eight waypoints and answered the questions, you will have completed one condition. You will then complete three fatigue and stress questionnaires. You will be given a five minute break and then you will complete a second trial. These trials will be conducted in exactly the same way and the only difference between the two trials will be the cues that will be presented to help orient you to the UAV images that are presented. After the second trial, you will again complete the fatigue and stress questionnaires. The two trials together with the questionnaires will take approximately 40 minutes to complete.

When finished with the G8 test session, you will be escorted to the HRED shooting simulator. You will be firing a de-milled M16A2 rifle at virtual targets, which will consists of friend and foe targets. You will shoot a total of 40, 24-target pop-up scenarios using friend and foe targets while adding simple numbers together that will either be presented on a visual display that you will be wearing on your forearm or through headphones. This shooting task along with the questionnaires will required a total of 30 minutes to complete. Prior to shooting, you will again be asked to complete fatigue and workload questionnaires.

Once you have completed the shooting simulation, you will have 1 ½ hours of free time. During this time you will be escorted to the participant waiting area or the dining area. While in the participant waiting room (during your free time), you will not be permitted to sleep; however, Xbox games, playing cards, coffee, etc. will be available to assist you in staying awake. There will be an experimenter present in the participant room. If you do begin to doze off, the experimenter will call your name and gently tap your shoulder. The experimenter will assist you in staying awake by talking to you or providing an escort to walk with you. At the end of your 1 ½ break, you will repeat the same sequence of events as described above. You will repeat this entire sequence (ACRA/Raven-Shield/G8/Shoot/Break) a total of eight times.

Breakfast, lunch, and dinner will be provided and you will be given ample time to eat. In addition, coffee, soda, and snacks will be available throughout the study. All food, drink, caffeinated beverages, and nicotine intake must be recorded throughout the study. You will receive a checklist for keeping track of this. This checklist will be monitored by the experimenter to ensure that you have consumed food at least every four hours and had a drink at least every two hours.

Please keep in mind that an escort is required at all times. This is not only for your own safety, but we are located in a security area and wandering around without an escort
is a security violation. If you need to use the facilities or attend to personal hygiene, ARL personnel will be available to escort you to the nearest restroom. Smoking is permitted in designated areas only. If you wish to take a smoke break, inform any one of the experimenters and an escort will be provided. On training day, you will be briefed as to the location of smoking areas, availability of snacks and dining, escort procedures, etc. The experimenters will keep track of where you go next and what you will be doing next, however, a test schedule will be posted in the participant waiting room and at each of the test stations in which you can track your own personal schedule of events.

Do not hesitate to ask questions or voice concerns. If at any time you feel ill or feel that you need medical attention, please tell one of the experimenters immediately. EMTs at the Kirk Army Health clinic will be alerted as to the nature of this study and will be available should you need medical attention.

At the end of the experiment, the heart monitor, wrist-watch, and temperature strip will be removed by one of the experimenters. You will then be escorted to Bldg 519 where you will be provided with 12 hours of uninterrupted rest. Cots, pillows, and blankets will be provided and an experimenter will be present during this time. If you need to use the facilities, an escort will be provided. At the end of the 12 hour rest period, you will be transported by the ARL back to your duty station.

Benefits

The ability to assess the cognitive readiness of the warfighter is critical to mission success. The present study will demonstrate the capabilities of a field usable assessment method that is designed to identify changes in the warfighter’s cognitive state due to a typical stressor, notably, fatigue. As a participant, you will receive the personal satisfaction of providing valuable information to Army cognitive sciences research. As a research institution, the ARL will obtain beneficial knowledge concerning the effectiveness of computer-displayed information while under moderate levels of arousal.

Risks

There are no direct physical or mental risks associated with participating in this study beyond the risks of playing a PC-based video game. The risks that may be encountered during this study are typical of the everyday risks encountered by soldiers.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. All examinations will be recorded using a volunteer identifier code and the Principal Investigator will keep your assigned volunteer identifier code in a locked cabinet. In order to ensure that your data will not be reported or revealed to anyone, each form will be reviewed upon receipt by one of the investigators. If any identifying information appears on the questionnaires (such as name, social security number, birth date, etc.), the investigators will delete the identifying information and replace it with a neutral code.
number.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The Principal Investigator will provide a copy of the signed and initialed Affidavit to you.

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee  OR  Office of the Chief Counsel
U.S. Army Research Laboratory  U.S. Army Research Laboratory

Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005  Adelphi, MD 20783-1177
(410) 278-4152 or (DSN) 298-4152  (301) 374-1070 or (DSN) 270-1070

I do hereby volunteer to participate in the research project described in this document. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the USAMRMC Human Subjects Research Chairperson at Ft. Detrick, MD, 21702-5012, USA by telephone at 301-619-7802. I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty.

Obtaining of ASVAB Scores

IF YOU ARE AN ACTIVE DUTY ENLISTED MILITARY VOLUNTEER, we would like to obtain your Armed Services Vocational Aptitude Battery (ASVAB) scores for potential data analysis. The ASVAB scores would be used strictly for research purposes. The results of any such analyses would be presented for the group of participants as a whole; and no names will be used. With your permission, we will obtain these scores by sending a copy of this signed consent form along with your Social Security Number to the Defense Manpower Data Center (DMDC) in Seaside, CA where ASVAB scores may be obtained from their databases in Arlington, VA or Seaside, CA. If you do not wish your ASVAB scores to be released to the principal investigator, you will still be allowed to participate in the research.

If you would like to participate in this research, please sign one of the following statements, and then complete the information requested at the end of this form:
I **DO AUTHORIZE** you to obtain my ASVAB scores.

______________________________
(Your Signature)

I **DO NOT AUTHORIZE** you to obtain my ASVAB scores.

______________________________
(Your Signature)

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<td><strong>Signature Of Volunteer</strong></td>
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<td><strong>Signature Of Administrator</strong></td>
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APPENDIX B

Stressor Appraisal Scale

Subject Number _________________________ Testing Session ____________________________

Please circle the number that best describes how you feel about the task you are about to perform. (7) indicates a maximum level and (1) indicates a minimum level. For example, if you are extremely threatened by the task you are about to perform (7) is the correct response for Item 1.

1. How threatening do you expect the upcoming task to be?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

2. How demanding do you think the upcoming task will be?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

3. How stressful do you expect the upcoming task to be?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

4. To what extent do you think you will need to exert yourself to deal with this task?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

5. How much effort (mental or physical) do you think the situation will require you to expend?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

6. How important is it for you to do well on this task?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

7. How uncertain are you about what will happen during this task?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

8. How well do you think you can manage the demands imposed on you by this task?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

9. How able are you to cope with this task?
   (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)

10. How well do you think you will perform on this task?
    (1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ (7)
APPENDIX C

Multiple Affect Adjective CheckList – Revised

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</table>
APPENDIX D

Army Cognitive Readiness Assessment (ACRA) Battery

TEST 1: RAPID DECISION MAKING

The ability to rapidly attend to a complex stimulus input, analyze it in relation to established rules and learned relationships, and then to choose between two or more alternatives through a motor action likely constitutes a "macro-cognitive" skill. In some cases, this involves an ability to "compartmentalize" stimulus inputs so that only information relevant to the required decision is allowed to enter into it. Since this ability is considered critical to so many activities, it is essential that it be measured, even though it is one of the more complex and difficult skills to probe.

In the past, we have used a simulation of the radar warning receiver (RWR) display as the stimulus element for probing this skill. In the present case, it was desirable to keep the essential elements of this test, but to generalize the skills involved, as well as making the test less complex.

The basic concept of this test is to present the subject with a display containing three "areas" that will represent three levels of unspecified "danger" (see Figure 1a). These areas will be clearly marked (optionally color coded) with respect to the level of danger. At various times, symbols will pop up on the display indicating that a "vehicle" has entered into one of the areas. The vehicle will appear as one of three types of symbol. One type will clearly indicate that the vehicle poses minimum threat, another will indicate that the vehicle is a medium threat, and third type will indicated that it is a critical threat. The subject's task is to decide on the level of threat, based on the type of vehicle and the area of the display in which it is located, and to make a differential response based on that decision. Location is always given higher priority than symbol type. For example, if a less threatening symbol is in the most dangerous area and the more threatening symbol is not, the less threatening symbol must be responded to. This is to be done as rapidly as possible, and the test will be paced so that only a short period of time will be available to make the decision before the next stimulus appears. In essence, this test is a complex choice reaction time test where higher level cognitive processes must be used to determine what the stimulus means.

Test Description

The simulation used in this test will consist of a round display containing two concentric rings creating three distinct areas within the display (see Figure 1a). The outer area is designated as an "alert” area, simulating a potential threat. The middle area is designated as a “danger” area, requiring some action. The third area is designated as a “critical” area, signifying that the threat is imminent. The circles may be colored (red = “critical,” yellow = “danger,” green = “alert”) or black and white.

The appropriate response by the subject will depend on the nature of the symbol that appears as well as where it appears. The three basic symbols and their threat levels are:

? = Minimal
O = Medium
X = Critical
Figure 1a. The RWR display: The upper images show the 3 rings that determine the criticality of response. The bottom images show an example of 3 objects which may appear on the RWR display. The object in the middle ring is a "medium threat" (O) and represents the greatest threat in this display. The figure on the left shows the display uncolored and the image on the right shows the display colored to reflect the criticality of the rings (Green = alert, Yellow = danger, Red = critical).

The symbols will all appear in the center of four quadrants in their respective areas of the display (i.e., they will not appear at the edges, so the subject does not have to make fine discriminations regarding which area they are in. The symbols may be small, but should be easily discriminated.
The experimenter is able to specify the actual number of trials to be presented. Once this number has been selected, actual stimulus presentation is randomized over the entire test, so that each of the nine combinations (three areas X three symbols) appears an equal number of times. No more than two consecutive presentations of a particular "area/symbol" combination will occur.

The logic of the response requirements for this test is based on selecting the highest probable threat. If the "X" is in the center (red) zone, or is closer to it than either of the other symbols, it is the highest threat, and should be responded to by pressing the designated button for the "X." If either the "O" or "?" are in the center area, that symbol should be responded to. If both of the other two symbols are closer to the center zone than the "X," then one of them represents the highest threat, and the subject must apply different rules to determine which to "attack." If the "O" is closer to, or the same distance from center than the "?," then the subject should designate the "O." If the "?" is closer to the center than either the "X" or "O," then it represents the greatest threat. The test procedures are set up so that ambiguous combinations can not be presented, so there will always be a correct answer.

The "timeout" period for any given stimulus should be approximately 2 seconds (although this may have to be adjusted after initial testing). If the timeout period is reached, the stimulus disappears and a new stimulus appears.

Response Devices

There will be three possible responses for this test, and all will be made on an appropriate response device. Response button selection should be made based on the ease with which the buttons can be reached and differentiated. If possible, buttons should be in positions that are equally easy to reach so that no systematic time differential will be introduced.

Training

It is envisioned that subjects will require a reasonable amount of training on this task in order to reach a stable plateau. The actual amount will have to be determined during initial testing, but it should be sufficient to assure that the majority of potential subjects will reach plateau.

TEST 2: TOWER OF HANOI

This is a classical clinical test that has been well validated as a probe of frontal lobe function in the brain. It is not well validated with regard to its sensitivity to minor frontal lobe deficits, but theoretically it appears to be a sensitive test of "executive planning" functions. As such, it is expected that more detailed analyses of the test will reveal subtle changes in an individual's ability to develop a plan, modify the plan as the situation changes, and in this way to continuously evaluate progress toward specific goal.

The test asks the subject to start out with a given configuration of objects, and to move them into another defined configuration, while following specific rules. Typically, 'doughnut-shaped' rings of different sizes are shown on one of three pegs. The goal is to move the rings to a designated peg so that they are in the same size relationship as they were when they started on the original peg. The major constraint is that in the process, no larger ring can be placed on a smaller one.

A great deal of research on the mathematical description of the processes that might be used by humans in attacking this problem has been carried out. In addition, NTI contracted with Klein Associates to determine the actual strategies used by subjects in solving the task. These
investigations have led to several hypotheses regarding innovative ways to analyze Tower of Hanoi data, described below.

**Technical Details**

The basic screen for this test (Figure 2a) shows three "pegs," protruding from square bases. The pegs are shown side-by-side, located equidistant from each other. All images (pegs, bases, and rings) are white against a black background, and are easily distinguishable from each other.

In the initial condition, the rings are all on the left peg, and are arranged from the largest on the bottom to the smallest on the top. Future versions of this test may start with random placement of the rings. Size of the various rings as well as peg height can be determined by the experimenter. The test provides the option to use at least six ring sizes, and they are sized so that there should be no confusion about whether one ring is smaller or the same size as another (i.e., each of the six sizes should be easily identified).

The subject will use the designated response device to press buttons that indicate the ring to be moved at each step. He or she will press the button corresponding to the peg from which they wish to remove a ring. In Figure 2a, the Subject would press the button for Peg 1. The subject will then press the button corresponding to the peg that he or she wishes to move the ring. This will result in the previously selected ring moving to that peg. In Figure 2b, the Subject pressed the button indicating Peg 2.

This procedure continues until the task of moving all rings to the designated peg is successfully completed. If the subject does not solve the problem in a designated time period (set in the INI file) then a time out is recorded. If the subject makes an illegal move (e.g., attempting to place a larger ring on a smaller one), an auditory tone is sounded. All such illegal moves (as well as all legal moves) are recorded in the data file.
In the default condition, we start with two rings (the 'training' condition described below) in order to determine that the subject understands instructions. If the subject does not know how to do this correctly, and after additional instructions can not do it, the test should not be administered to that subject. Actual testing will begin with three rings on the left peg. If the subject eventually solves this problem, proceed to the four ring problem. Similarly, if that problem is solved, proceed to the five ring problem, and then to the six ring problem. If the subject has solved the four, five, and six ring problem in the minimum number of moves possible he or she will be considered "passed,” and further analyses of data will not be necessary. On the other hand, if the subject has not solved either the three, four, five, or six ring problem in an optimal way we would like to analyze the errors in more detail.

**Training**

Training on this test should consist of presentation(s) of the two ring problem until it is clear that the subject understands the goal and restrictions of the problem. Obviously, this is a simple training situation, and only a severely decremented subject would be unable to understand the task's demands. Therefore, training time should be short -- on the order of less than 5 minutes. In practice, however, the test administrator should be able to repeat the two ring problem as often as he/she wishes.
Instructions to the subject should include the following points:

This is a test of how well you can develop a plan in order to reach a defined goal. You will see three upright pegs. On the left peg, you will see rings of different sizes. The largest ring will always be on the bottom, and each ring above it will always be smaller. No bigger ring will ever be on top of a smaller ring. Your goal will be to move the rings to the right peg so that they are in the same position as they were on the left peg (largest on bottom and smallest on top) and to do this in the shortest number of moves.

You will move the rings by pressing the response button assigned to the peg containing the ring you wish to move. Then press the response button assigned to the peg to which you want the ring moved.

Testing instructions

Once it is assured that the subject understands the basic requirements of the test, only the following instructions need to be given:

Now you understand that your goal is to move the rings from the left peg to the right one in as small a number of moves as possible. Remember that you can use the middle peg as often as necessary. The test will now present more rings and a much more challenging task. Remember that you may never place a larger ring on a smaller ring. Your score on this test will depend on the efficiency of the moves you make. The smaller number of moves, and the more quickly you make them, the higher your score. However, it is best to take time and think about an overall strategy before making moves. You should think about the goal and the best way to arrive at that goal.
## APPENDIX E

Participant Food and Water Log

### Subject 1

| Time | Food Item 1 | Food Item 2 | Food Item 3 | Food Item 4 | Food Item 5 | Water Drink | Coffee | Tobacco | Food Item 1 | Food Item 2 | Food Item 3 | Food Item 4 | Food Item 5 | Water Drink | Coffee | Tobacco |
|------|-------------|-------------|-------------|-------------|-------------|-------------|--------|---------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------|---------|
| 6:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 7:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 8:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 9:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 10:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 11:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 12:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 13:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 14:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 15:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 16:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 17:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 18:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 19:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 20:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 21:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 22:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 23:00|             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 0:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 1:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 2:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 3:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 4:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 5:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 6:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 7:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |
| 8:00 |             |             |             |             |             |             |        |         |             |             |             |             |             |             |         |         |


**APPENDIX F**

Selected Covariance Structure Types for Independent and Dependent Factors

<table>
<thead>
<tr>
<th>Metric/Covariance Structure</th>
<th>Scaled-Identity df</th>
<th>Diagonal df</th>
<th>AR1</th>
<th>ARH1</th>
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<tbody>
<tr>
<td>SAS-ACRA</td>
<td>239</td>
<td>192</td>
<td>12</td>
<td>p=.000</td>
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<tr>
<td>NA-ACRA</td>
<td>800</td>
<td>819</td>
<td>12</td>
<td>p=.000</td>
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<td>Anxiety-ACRA</td>
<td>727</td>
<td>737</td>
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<td>Depression-ACRA</td>
<td>857</td>
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<td>Hostility-ACRA</td>
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<td>797</td>
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<td>SAS-Combat</td>
<td>96</td>
<td>112</td>
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<td>PA-Combat</td>
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<td>NA-Combat</td>
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<td>836</td>
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<td>Anxiety-Combat</td>
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<td>12</td>
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<td>Depression-Combat</td>
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<td>843</td>
<td>12</td>
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<tr>
<td>Hostility-Combat</td>
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<td>862</td>
<td>12</td>
<td>p=.000</td>
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<tr>
<td>RDM-Percent Correct</td>
<td>591</td>
<td>585</td>
<td>12</td>
<td>p=.554</td>
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<tr>
<td>RDM-RT Variability</td>
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<td>(-)71</td>
<td>12</td>
<td>p=.070</td>
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<tr>
<td>RDM-Number Misses</td>
<td>417</td>
<td>358</td>
<td>12</td>
<td>p=.424</td>
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<tr>
<td>TH-Number Moves</td>
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<td>357</td>
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<td>p=.526</td>
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<td>TH-Total Time</td>
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<td>644</td>
<td>12</td>
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<td>TH-Errors</td>
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<td>315</td>
<td>12</td>
<td>p=.667</td>
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<tr>
<td>Enemy Kills</td>
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<td>424</td>
<td>12</td>
<td>p=.897</td>
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<td>Mine Kills</td>
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</tr>
<tr>
<td>Civilian Fire</td>
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<td>252</td>
<td>12</td>
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<tr>
<td>Number Casualties</td>
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<td>401</td>
<td>12</td>
<td>p=.001</td>
</tr>
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</table>

*Diagonal must be 11.07 points smaller than Scaled Identity in order to model for Heterogeneity.*