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I, ______Lauren Reinerman______________, hereby submit this work as part of the requirements for the degree of:

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Cerebral Blood Flow Velocity and Stress as Predictors of Vigilance

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Abstract

Vigilance or sustained attention is a critical aspect of many jobs including air-traffic control, airport security, industrial quality control, and medical screening/monitoring. Traditional approaches to personnel selection for tasks requiring sustained attention have focused on sensory acuity, aptitude, sex, age, and personality measures. However these approaches have been ineffective. The present study attacked the selection issue in an innovative manner by using responses to a brief 10-min screening battery involving high workload tracking, verbal working memory, and line discrimination tasks to predict performance on a subsequent vigilance task. The latter simulated an air-traffic control task and was composed of four consecutive 9-min periods of watch. Two predictors of interest were cerebral blood flow velocity (CBFV), measured via transcranial Doppler ultrasonography (Warm & Parasuraman, 2007), and subjective state, as indexed by the Dundee Stress State Questionnaire (DSSQ; Matthews, et al; 2002). The results testify to the importance of assessing task-induced responses for predicting vigilance performance. They also indicate that forecasting vigilance performance is a complex endeavor requiring a set of multidimensional predictors. Specifically, multiple regression ($R = .358$) indicated that higher levels of CBFV in the left and right hemispheres and higher post-battery task engagement scores on the DSSQ during performance of the screening battery predicted perceptual sensitivity (A’) during the final period of watch when performance deficiencies are most likely to occur. Predictions from a correlation of this magnitude, which accounts for 9.7 percent of the variance when adjusted for shrinkage, can lead to an increase in job success rate of 40 to 60 percent (Koelega, 1992; Rosenthal & Rubin, 1982). These findings were interpreted theoretically in light of a resource model of vigilance proposed by Davies & Parasuraman (1982).
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Chapter 1

General Introduction

Vigilance: A Human Factors Problem

*World War II Origins.* Vigilance, or sustained attention, is the ability of an observer to detect and respond to infrequent critical signals over an extended period of time. Sir Henry Head (1923) initially employed the term “vigilance” to describe a state of maximum physiological and psychological readiness to react (Davies & Parasuraman, 1982). However, the first systematic investigation of vigilance dates back to World War II when Norman Mackworth (1948; 1950/1961) was commissioned by the Royal Air Force to study an unexpected and potentially perilous finding in the performance of airborne British radar observers on anti-submarine patrol over the Bay of Biscay. Radio detection and ranging, or radar, was a major technological innovation of the time and was utilized by the military for watchkeeping or surveillance tasks. As their watch progressed, however, well-trained and highly motivated observers began to miss “blips” on their pulse-position radar displays that indicated surfaced submarines, resulting in the U-boats’ continued ability to prey freely upon allied ships.

To study sustained attention performance experimentally, Mackworth used a simulated radar display called the “Clock Test,” in which observers viewed a black pointer that “jumped” 0.3 inches from one spatially adjacent position to another along the circumference of a blank-faced clock that was devoid of any scale markings or reference points. Pointer movements occurred at a rate of one/sec. Critical signals for detection were occasional “double jumps” of 0.6 inches. Observers were tested individually on this task, which lasted continuously for two hours. They signified their detection of critical signals by means of a button-press response. The signals were clearly perceptible when observers were alerted to them, but were not dynamic changes in
the operating environment. Signals occurred infrequently (approximately 3% to 5% of the time) in a temporally uncertain manner and their appearance was in no way influenced by the observers’ responses. Mackworth’s approach to the experimental study of vigilance became the standard paradigm in this area of investigation (Warm, 1984).

Using the “Clock Test,” Mackworth charted the course of vigilance performance in the laboratory and confirmed suspicions generated in the field that sustained attention is fragile; it declines quickly over time. From an initial level of 85% detections at the outset of Mackworth’s study, the frequency of correct detections by observers decreased to 75% within the first 30-minutes of watch and continued to drop for the remainder of the 2-hour vigil. The progressive decline in performance efficiency across time noted in Mackworth’s original experiments is known as the vigilance decrement or the decrement function.

Current Interest in Vigilance. The decrement function has been repeatedly confirmed in a substantial body of subsequent investigations and is the most ubiquitous finding in vigilance research (Ballard, 1996; Davies & Parasuraman, 1982; Matthews, Davies, Westerman, & Stammers, 2000; See, Howe, Warm, & Dember, 1995; Warm, 1984). In general, the majority of the decrement occurs within the first 15 minutes on watch (Teichner, 1974). It can even be seen in the first five minutes of the task when signals are presented in especially demanding circumstances (Helton, Dember, Warm, & Matthews, 2000; Jerison, 1963; Nuecterline, Parasuraman, & Jiang, 1983; Rose, Murphy, Byard, & Nikzad, 2002; Temple et al., 2000). The decrement has been found to occur with experienced observers, as Mackworth showed, as well as with inexperienced observers. Further, this effect has been found in operational environments in addition to laboratory settings (Baker, Ware, & Sipowicz, 1962; Colquhoun, 1961; 1977; Pigeau, Angus, O’Neil, & Mack, 1995; Schmidke, 1976). Today, human factors and ergonomics
specialists are particularly concerned with this aspect of human performance due to the significant role that vigilance plays in many automated human-machine systems (Davies & Parasuraman, 1982; Howell, 1993; Koelega, 1992; Parasuraman, 1986; Proctor & Van Zandt, 1994; Warm, 1993; Parasuraman, Warm, & Dember, 1987; Wickens, Gordon, & Liu, 1998).

Modern technology has allowed automation to be utilized in a variety of operational settings. As a result, human operators’ duties have shifted from manual control to supervisory control in which their responsibilities include executive functions wherein they monitor displays and act only in instances of problems or system failures (Sheridan, 1970). Therefore, vigilance is a principal element of human performance in a wide range of activities including air traffic control, airport security, military surveillance, industrial quality control, nuclear power plant regulation, long distance driving, robotic manufacturing, and agricultural operations, as well as cytological screening and the inspection of anesthesia gauges during surgery (Hancock & Hart, 2002; Hartley, Arnold, Kobryn, & Macleod, 1989; Warm, 1984;1993; Gill, 1996; Wyatt & Langdon, 1932; Warm & Dember, 1998; Weinger & Englund, 1990).

A primary reason for employing automation in work environments is to improve efficiency by decreasing the information-processing demand imposed on operators (Parasuraman, 1986; Weiner, 1984; 1985). However, this reduction has both beneficial and costly consequences. Disastrous accidents, such as nuclear power plant meltdowns and airplane crashes, have been linked to poor operator vigilance in the control of automated systems (Molloy & Parasuraman, 1996). One solution to this dilemma would be to design systems that eliminate the need for a human component. However, as Parasuraman (1986) has noted, individuals in automated systems cannot be completely bypassed because humans are ultimately needed to act in a fail-safe capacity in the instance of system malfunction. Given the importance of being able to sustain attention
properly for system reliability and productivity and for public safety (Nickerson, 1992; Warm & Dember, 1998), a key human factors concern is the selection of personnel that are best suited for positions requiring this capacity (Casagrande, Violini, Crucio, & Bertini, 1997; Craig, 1984). That problem was the focus of this investigation.

**Traditional Approaches to Selection**

*Sensory Acuity and Aptitude Measures.* Since signal detection is the crucial goal in performing vigilance tasks, an obvious dimension on which to focus selection measures would be sensory acuity. This dimension has, however, provided disappointing results within the normal ranges of vision and hearing. Within these ranges, several studies have reported that observers with the most acute vision or hearing do not necessarily make the best monitors (Baker, 1960; Baker, Ware, & Sipowicz, 1962; Tiffin & Rogers, 1941; Megaw, 1979; Nelson & Barany, 1969). Paradoxically, sensory impairment has been found to be a beneficial factor in vigilance performance. Bendetti and Loeb (1972) have reported that blind observers performed more effectively than sighted observers on an auditory vigilance task and Dittmar, Berch, and Warm (1982) found superior performance for deaf as compared to normal hearing observers on a visual vigilance task. The utility of these findings for the selection issue is limited, however, by the availability and acceptance of blind and deaf observers for monitoring assignments in operational environments such as military surveillance, airport security, or medicine.

Davies and Parasuraman (1982) have pointed out that individuals vary in the frequency and type of errors that they make in vigilance tasks and in terms of the extent of the vigilance decrement. Indeed, they note that individual differences can often be a source of variance as great as or greater than that due to task or environmental factors. Consequently, the search for aptitude measures that would reliably predict vigilance performance has played a large role in efforts to
develop selection procedures for vigilance assignments as it has in the selection for a wide variety of other tasks (Ackerman & Cianciolo, 2000). Like sensory acuity, this approach has also met with disappointing results. Most of the studies on the aptitude correlates of vigilance performance have focused upon general intelligence. While there is some evidence of a positive correlation between levels of normal intelligence and vigilance (Stankov, 1983), comprehensive reviews by Berch and Kantor (1984), Craig (1984), Davies and Parasuraman (1982), and McGrath (1963) have reported that within the normal range, there is essentially no significant relation between measures of general intelligence and vigilance. To be sure, McGrath (1963) concluded that efforts to select on the basis of IQ would be a dead end.

In addition to intelligence, McGrath (1963) examined a wide variety of psychometric properties involving dimensions such as arithmetic reasoning, visual speed and accuracy, memory span, mechanical and clerical aptitude, visual pursuit, proof-reading, and audio-visual checking and was unable to uncover any reliable predictors of vigilance performance. Later reviews by Craig (1984), Davies and Parasuraman (1982), and Wiener (1975) have affirmed that the search for psychometric aptitude measures has been unproductive. A possible reason for the barren nature of this approach to selection for vigilance assignments comes from a study by Levine, Romashko, and Fleishman (1973) indicating that vigilance tasks can be classified into those demanding different types of perceptual and cognitive abilities such as perceptual speed (the speed with which sensory patterns are compared in order to identify difference), flexibility of closure (the ability to isolate relevant stimuli from distractions), selective attention (the ability to perform under monotonous conditions), and time sharing (the ability to utilize data from two or more channels of information). Consequently, the search for a single inclusive attribute for selection may be destined to fail. An alternative approach to aptitude selection for vigilance in
operational settings involves correlations with supervisors’ ratings. However, these measures have been criticized for poor reliability and validity, first by Mills and Sinclair (1976) and more recently by Wickens, Mavor, and McGee (1997). Perhaps the most direct approach to the aptitude issue is to base selection on a sample of the vigilance task itself. An approach of this sort is tied to observations that the performance of observers on a vigilance task is reliably consistent from one testing session to another (Gunn & Loeb, 1967; Jerison & Pickett, 1963; Wallis & Samuel, 1961). However, as noted in a careful review by Craig (1984), the results secured from the task-sampling approach are equivocal, some studies showing successful prediction outcomes others not.

Sex and Age. Two of the most obvious dimensions on which people differ are sex and age. Accordingly, investigators have explored the possibility that these dimensions may predispose individuals to perform better on vigilance tasks. However, that possibility, like those above, has not borne fruit. Davies and Tune (1969) best describe sex differences in vigilance by categorizing the inconclusive findings as women being superior to men, men being superior women, and no sex differences.

An early example of performance differences favoring women is a study by Whittenburg, Ross, and Andrews (1956), which featured the Clock Test in a two-hour vigil. A gradual decline in performance was found for both men and women across the first hour with a sharp decline throughout the second hour of observation only for men. Taub and Osborne (1968) later confirmed these results. Another study, conducted by Bakan and Manley (1963), involved blindfolding a portion of the group of observers while they listened to a 48-min tape recording of single digit numbers with critical signals for detection being three odd digits in a row. Blindfolded males performed better than non-blindfolded males, whereas females’ performance remained high regardless of the blindfold.
Rivaling the studies just described, several investigations have reported just the opposite effects-- superior performance of males over females. Neal and Pearson (1966) utilized the identical vigilance task as Bakan and Manley (1963) except that the task duration was extended to 64-min. Contrary to the earlier study, they found that females performed more poorly than males, missing significantly more signals throughout the watch. Waag, Tyler, and Halcomb (1973) had observers monitor the movement of a bar of light for occasional longer movements and Dittmar, Warm, and Dember (1987) asked observers to monitor the repetitive presentation of pairs of lines for occasional increments in height. In both of these studies, males detected more critical signals than females. In addition, Coules and Avery (1966) have reported that reaction times to the detection of critical signals were faster for men than for women, a result that has been confirmed by Giambra and Quilter (1989).

Research surrounding sex differences in vigilance performance is further complicated by studies reporting neither male nor female superiority. Lucaccini and his associates (Lucaccini, Freedy, & Lyman, 1968; Smith, Lucaccini, & Epstein, 1967) found no sex differences for a one-hour task entailing the observation of a small window through which white tape was pulled that contained solid geometric shapes representing targets and two types of distracters. An absence of sex differences was also found in other studies utilizing a variety of psychophysical manipulations. These studies include the manipulation of noise by Kirk and Hecht (1963), the manipulation of interstimulus intervals by McCormack (1958; 1959; 1960), and the manipulation of sensory modality by Hawkes and Loeb (1961), as well as a tracking task by Loke and Meliska (1984) and a visual target detection task by Tolin and Fisher (1974) and Parasuraman and Davies (1976).

A final complexity in the portrayal of sex differences in vigilance is a report by Dittmar,
Warm, Dember, and Ricks (1993) in which performance efficiency favored males in a task in which spatial factors were involved in signal detection but there were no sex differences in a task of similar difficulty that required temporal discrimination. A result of this sort suggests that vigilance differences between the sexes may be task specific. The abundance of conflicting and/or equivocal results in regard to sex differences in vigilance has led Berch and Kantor (1984) and Davies and Parasuraman (1982) to conclude that such differences serve little or no practical or theoretical purpose, a conclusion echoed by Ballard (1996). The absence of definitive evidence for sex differences in vigilance may fit with the emerging view that men and women are more similar than different on many psychological variables (Hyde, 2005).

Age, too, is an unreliable predictor of vigilance performance. An extensive longitudinal study by Quilter, Giambra, and Benson (1983), in which observers were tested over a period of several years, suggested that there was a marked fall in detection efficiency at or around the age of 70 years. However, this finding was not confirmed in a later longitudinal study by Giambra and Quilter (1988) in which age differences in detection accuracy were not observed. For the most part, studies of age effects in vigilance have been cross-sectional in nature wherein different cohorts are compared across age levels at a given point in time. While a number of these studies have not revealed any age-related differences in vigilance performance (Davies & Griew, 1963; Neal & Pearson, 1966; York, 1962), others have shown that younger observers perform better than their older cohorts (Bicknell, 1970; Canestrari, 1963; Deaton & Parasuraman, 1993), particularly when signal/noise discriminations are difficult (Parasuraman, Nestor, & Greenwood, 1989) and the background event rate or the rate of presentation of stimulus events to be examined for the presence of critical signals is rapid (Davies, 1968; Talland, 1966; Thompson, Opton, & Cohen, 1963). To some extent, age differences also depend upon physical fitness with the
performance of older less fit observers falling below that of their more fit older cohorts and younger observers (Bunce, Barrowclough, & Morris, 1996). Given the inconsistencies and the complexities noted in the age/vigilance relation, age does not appear to be a promising factor in the hunt for ideal monitors.

**Personality.** Traditional approaches to selection for vigilance have long noted the possibility that personality factors may provide a key to identifying observers who are most suited for vigilance assignments (Ballard, 1996; Bakan, Belton, & Toth, 1963; Craig, 1984; Davies & Parasuraman, 1982; Wiener, 1975). Along that line, several dimensions have been recognized including boredom proneness, cognitive failure, propensity to daydream, locus of control, the coronary-prone behavior pattern, and field dependence/independence.

As described by Geiwitz (1966), boredom is associated with feelings of increased constraint, repetitiveness, unpleasantness, and decreased arousal. Given the repetitive and constrained nature of vigilance tasks, one would anticipate that such tasks would induce considerable levels of boredom. This is indeed the case (Hitchcock, Dember, Warm, Moroney, & See, 1999; Jerison, Pickett, & Stenson, 1965; Scerbo, 1998) and the degree of boredom is related to performance efficiency. Studies by Bakan (1959), Sawin and Scerbo (1995), Scerbo (1998), and Thackray, Bailey, and Touchstone (1977) have reported that signal detection varies inversely with the degree of boredom experienced while performing vigilance tasks.

In recent years, human factors specialists have devoted considerable interest to lapses of attention or absent-mindedness as a source of accidents (Reason, Manstead, Stradling, Baxter, & Campbell, 1990). Since vigilance assignments require observers to focus their attention to displays for considerable periods of time, those who are prone to approach tasks with a lack of attentional focus may not be well suited for such assignments. Robertson and his associates
(Manley, Robertson, Galloway, & Hawkins, 1999; Robertson, Manley, Andrade, Baddeley, & Yiend, 1997) tested this possibility using the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, Fitzgerald, & Parkes, 1982), a self-report instrument that measures lapses of attention, slips of action, and failures of everyday memory. Consistent with their expectation, they found that absent-minded individuals, defined by high scores on the CFQ, do more poorly on vigilance than those who have low scores. In another study, Grubb et al., (1994) reported that high cognitive failure individuals also find the vigilance task to induce greater levels of perceived mental workload than their low cognitive failure counterparts.

Related to the issue of absentmindedness and cognitive failure is the propensity to daydream. Antrobus, Coleman, and Singer (1967) explored the possibility of a relation between daydreaming and vigilance by dividing observers into high and low groups on the basis of the Singer and Antrobus (1963) daydreaming scale and found that the high daydreaming group showed a vigilance decrement while performance remained stable over the course of the vigil for observers in the low daydreaming group. In addition, they found that task-unrelated thoughts or shifts of attention away from the task at hand (TUTS) increased over time for both groups but more so for observers in the high than in the low daydreaming group. In that study, observers were queried about TUTS by periodic signals to which they answered in the affirmative by pressing a response switch. The results regarding TUTS were verified in a later study by Giambra (1993). Both of these experiments are consistent with a study by Bakan, Belton, and Toth (1963) who reported that observers agreeing with the statement, “I was completely lost in my daydreaming,” administered post-vigil, performed more poorly than those who disagreed with that statement.

As noted earlier, a key aspect of vigilance tasks is the lack of control that observers have
over signal occurrences. Consequently, one might anticipate that within Rotter’s (1966) locus of control dichotomy, observers who believe that they control their own destiny (internal locus of controls) would be more tenacious in the face of signal uncertainty than those who feel that their fate is contingent primarily upon external factors (external locus of controls). This idea was pursued by Sanders, Halcomb, Fray, and Owens (1976) who showed that internals were superior to externals in the performance of a vigilance task.

Another aspect of the vigilance task, the need to be able to resist distractions, led Lunberg, Warm, Seeman, and Porter (1979) to propose that the coronary prone behavior pattern in which Type A individuals, those characterized by a rushed, competitive, achievement-oriented life style, would be more able to resist distractions than their more relaxed Type B counterparts and would therefore be better watchkeepers than Type B’s. Consistent with that view, they found a superior level of signal detection in Type A’s than Type B’s. Similarly, the idea that field independent individuals, as measured with the classic Rod and Frame test, are better able than field dependent individuals to focus on relevant aspects of the environment and ignore irrelevant features (Witkin et al., 1954) primed experiments by Cahoon (1970), Moore and Gross (1973), and Ware and Baker (1977), which demonstrated the need to consider field dependence/independence as a selection dimension for vigilance since the performance of field independent observers is superior to that of field dependent observers.

A key element in the research on personality and vigilance just described is that while on an individual basis the studies were conceptually driven by matching trait characteristics to elements of task demand, they were essentially unrelated to each other. As Berch and Kantor (1984) have noted, such a montage of components provides a serious problem for the selection issue because there are little data to indicate how these factors would influence vigilance
performance when consolidated within the same individual, and it is unlikely that one could find enough individuals possessing various trait combinations to make meaningful performance predications. Current efforts in the personality area to provide a taxonomy that blends a wide variety of traits into a limited number of higher-order abstract terms (see Matthews, Deary, & Whiteman, 2003) may serve to attenuate this problem in selection for vigilance. One such taxonomy is Costa and McCrae’s (1992) “Five Factor Model”, a psychometrically-sound broad personality representation that includes the widely accepted traits of Extraversion, Neuroticism, Conscientiousness, Agreeableness, and Openness (Matthews, Deary, & Whiteman, 2003) These traits have been invariant across age, sex, and culture and have demonstrated predictive utility in explaining a variety of abilities and behaviors ranging from memory and learning skills to real world applications like job selection and performance (Barrick & Mount, 1991; Costa & McCrae, 1992; DeFuyt & Merviede, 1999; Matthews, 2001; Matthews & Deary, 1998). In that regard, two of the “Big Five” traits, extraversion and conscientiousness, have been found to be related to vigilance performance.

Extraverts are described as outgoing individuals who exhibit high levels of sociability and assertiveness whereas introverts are typically quiet and reserved. In general, introverted observers’ performance on vigilance tasks exceeds that of their extroverted counterparts (Koelega, 1992; Rose et al., 2002), a result which has been explained by psychobiological theories of personality in which a cortico-reticular circuit controlling alertness is proposed to be more readily activated by stimulation in introverts than in extraverts (Eysenck, Eysenck, & Barrett, 1985). Conscientiousness, which encompasses attributes of competence, dutifulness, order, achievement striving, self-discipline, and deliberation (Costa & McCrae, 1992), would appear to be a trait that would be beneficial to the successful completion of a tedious, time demanding task such as
vigilance. Indeed, a positive relation between conscientiousness and vigilance performance was established in a recent study by Rose and her associates (2002).

Although the “Big Five” model has promise for the development of an economical tool by which to select people for vigilance assignments on the basis of personality traits, considerable more work needs to be done along this line. With regard to extraversion, an extensive review of 53 studies by Koelega (1992) led him to point out that effect sizes were small, inconsistent across studies, and task dependent -- greater for visual than auditory tasks. These findings were substantiated by Amir et al. (2001), Costa and McCrae (1992), Rose et al. (2002), and Schmidt, Beauducel, Brocke, and Strobel (2004). Moreover, the study by Rose and her colleagues (2002) is, to date, the only experimental effort to explore the relation between the conscientiousness dimension and vigilance.

**An Alternative Approach to Selection**

*Information-Processing Resources.* At this point, it is evident that traditional approaches to selection for vigilance have not been especially productive. What may be needed is a new direction for research on the selection issue. Such a direction was the basis for the present study.

Vigilance tasks have traditionally been viewed as understimulating assignments that impose little demand upon observers (Frankmann & Adams, 1962; Nachreiner & Hanecke, 1992). Warm, Dember, and Hancock (1996) have noted, however, that this view stems from a superficial task analysis, one not based upon the actual degree of underload inherent in these tasks. When the information-processing load or the resource demands imposed by vigilance tasks were measured, the cost of mental operations in vigilance was found to be substantial. Using the NASA-Task Load Index (NASA-TLX; Hart & Staveland, 1988), a well regarded measure of perceived mental workload or the resource demands associated with task performance (Wickens
& Hollands, 2000), an extensive series of studies by Warm and his colleagues (1996) found that the workload scores associated with vigilance tasks fell at the upper level of the scale with mental demand and frustration being the primary components of the workload imposed by those vigilance tasks (see also a review by Finomore, 2006). Resource theory is the dominant theoretical approach to the assessment of mental workload and provides a major conceptual framework for understanding vigilance performance (Parasuraman, Warm, & Dember, 1987; Wickens, 2002). Johnson and Proctor (2004) have recently concluded that the perceived mental workload studies support a resource model of vigilance proposed by Parasuraman and his associates (Davies & Parasuraman, 1982; Parasuraman, 1979; Parasuraman & Davies, 1977; Parasuraman, Warm, & Dember, 1987; Warm & Dember, 1998) in which the vigilance decrement is attributed to a progressive loss of information-processing entities or resources that are not replenished over time.

Given the key role played by resource theory in accounting for vigilance performance, our ability to develop predictive measures of vigilance performance may be improved by assessment of individual differences in resource availability and utilization (Matthews, Davies, & Holley, 1993). Toward that end, the strategy adopted in this study was to expose observers to a short, potentially stressful battery of high information-processing demand tasks. Responses to the battery were then used for assessment of resource availability, providing a basis for predicting subsequent vigilance task performance. Two types of responses were considered to be promising as indices of resources. One was a physiological measure, cerebral blood flow velocity (CBFV), indexed via Transcranial Doppler Ultrasonography (TCD; Stroobant & Vingerhoets, 2000; Tripp & Warm, 2007). The other was a subjective state measure, task engagement, indexed via the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999; 2002).
Transcranial Doppler Ultrasonography. TCD is a noninvasive neuroimaging technique that employs ultrasound signals to monitor cerebral blood flow velocity (CBFV) or hemovelocity in the mainstem intracranial arteries – the middle, anterior, and posterior cerebral arteries (the MCA, ACA, and PCA, respectively.) These vessels are readily isonated through a “transtemporal window” and exhibit discernable measurement characteristics that facilitate their identification (Aaslid, 1986; Tripp & Warm, 2007). The TCD technique uses a small 2 MHz pulsed Doppler transducer to gauge cerebral arterial blood flow velocity. The transducer is placed just above the temporal bone, a part of the skull that is functionally transparent to ultra-sound. The depth of the pulse is adjusted until the desired intracranial artery is isonated. The MCA is used most often because it carries approximately 80 percent of the blood flow within each cerebral hemisphere (Aaslid, 1986; Toole, 1984). TCD measures the difference in frequency between outgoing and reflected energy as it strikes moving erythrocytes. The low weight and small size of the transducer and the ability to embed it conveniently in a headband permit real-time measurement of CBFV while not limiting or being hampered by body motion. Therefore, TCD enables inexpensive and continuous monitoring of CBFV in both the right and left cerebral hemispheres concurrent with task performance.

When a particular area of the brain becomes metabolically active, as in the performance of mental tasks, by-products of this activity such as carbon dioxide (CO$_2$) increase. This increase in CO$_2$ leads to a dilation of blood vessels serving that area, which, in turn, results in increased blood flow to that region to carry away the waste product. (Aaslid, 1986; Risberg, 1986). Consequently, as Stroobant and Vingerhoets (2000) have noted, TCD offers the possibility of measuring changes in metabolic resources during task performance. In this regard, it is important to note that the diameters of the MCA, ACA, and PCA remain largely unchanged under varying task demands,
indicating that the hemovelocity changes in these larger arteries from which TCD measurements are obtained do not result from their own vascular activity; they derive instead from changes in the blood demanded by their profusion territories and thus changes in local neuronal activity (Duschek & Schandry, 2003; Tripp & Warm, 2007).

TCD has been used in medicine for many years for monitoring fetal heartbeat, evaluating blood flow in the carotid arteries, and for neurological diagnosis (Babikian & Wechsler, 1999; Tripp & Warm, 2007). In psychology, it has been used to measure changes in CBFV that occur in the performance of a wide variety of tasks ranging from simple signal detection to complex information-processing in reading, solving mathematical problems, performing a visual search task, and making ethical decisions. The general trend is that task performance is accompanied by increases in CBFV over a resting baseline and that the TCD changes co-vary with the cognitive demand imposed by the task (see reviews by Duschek & Schandry, 2003; Klingelhofer, Sander, & Wittich, 1999; Stroobandt & Vingerhoets, 2000; Tripp & Warm, 2007). Along with early work by Schnittger, Johannes, Arnavaz, and Munte (1997), extensive studies by the human factors group at the University of Cincinnati (Shaw, 2006; Beam; 2002; Hollander, 2002; Warm & Parasuraman, 2007) have used the TCD procedure to measure CBFV during the performance of a vigilance task. These studies have shown that increments from baseline CBFV vary directly with task demand. For example, greater levels of CBFV have been found when signal detection requires working memory than when it does not, or when signal detection requires symbolic as compared to simple sensory discriminations. Moreover, these results appear primarily in the right cerebral hemisphere, suggesting the operation of a right hemispheric system in the control of vigilance performance. In addition, these studies also show that the vigilance decrement is accompanied by a parallel decline in CBFV over time but only when observers must actively engage the vigilance task. Blood flow
velocity remains stable over time when observers merely gaze at a visual display or listen to an auditory display without a work imperative. Given that CBFV is closely tied to information-processing demand in vigilance and in a wide variety of other tasks as well, the present study was designed to test the possibility that the level of CBFV secured from observers on the short battery might be of value in predicting the overall level of performance and the severity of the vigilance decrement on a subsequent attentionally demanding vigilance task.

Stress and the DSSQ. In addition to imposing a high level of information-processing demand upon observers, vigilance tasks have also been found to be stressful and the stress reactions to these tasks may provide an additional dimension for selection. The concept of stress has been defined in a variety of conflicting ways in the literature (Matthews, 2001). For the purposes of this study, the transactional approach offered by Lazarus and Folkman (1984) was utilized, which depicts stress states as abstracted representations of the relation between individuals and the demands placed upon them. In terms of this view, individuals experience psychological stress when they appraise their environment as exceeding their available resources and/or as jeopardizing their physical or emotional well-being. The Lazaraus and Folkman (1984) definition enjoys considerable acceptance in the stress literature (Matthews et al., 1999) and fits well with the information-processing approach on which this study was based.

One way to examine the stress induced by vigilance or sustained attention tasks is through self-reports of subjective states after participating in a vigil. An early study along this line was reported by Thackray and his associates (1977). Using a simple 9-point scale, these investigators found that observers in a vigilance task reported feeling much less attentive and more strained, irritated, and fatigued after a vigil than before its start. These results have been replicated in several subsequent studies (Hovanitz et al., 1989; Lunberg, Warm, Seeman, & Porter, 1980;
Thiemann, Warm, Dember, & Smith, 1989; Warm, Rosa, & Colligan, 1989). Studies using the Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) and the Yoshitake Symptoms of Fatigue Scale (Yoshitake, 1978) have reported increased feelings of sleepiness and fatigue following a sustained attention task (Dittmar, Warm, Dember, & Ricks, 1993; Galinsky et al., 1993; Thiemann et al., 1989; Warm, Dember, & Parasuraman, 1991) and as indicated in an earlier section, observers have reported heightened feelings of boredom while performing a vigilance task (Bakan, 1963; Hitchcock et al., 1999; Scerbo & Sawin, 1994; Sawin & Scerbo 1995; Scerbo 1998; Thackray et al., 1977).

Although the studies just described have been successful in portraying the stress of sustained attention, the report measures they employed are limited because they focused upon unitary stress dimensions. A key aspect of the current understanding of stress is that it is a multidimensional construct and therefore the experience of stress may involve affective, cognitive, and motivational domains (Hockey, 1997; Matthews et al., 1999; 2002). To address this issue, Matthews and his associates (1999; 2002) developed the DSSQ to assess transient states associated with mood, arousal, and fatigue. This instrument features ten factor-analytically determined scales which measure energetic arousal (alertness-sluggishness), tense arousal (nervousness-relaxation), hedonic tone (general feelings of happiness-cheerfulness), intrinsic task motivation, self-focused attention (self-awareness-daydreaming, etc.), self-esteem, concentration, confidence and control, task relevant cognitive interference (worry about task performance), and task irrelevant cognitive interference (self-oriented thoughts that are not task related). These scales have been incorporated into three factor-analytically derived dimensions known as Task Engagement, Distress, and Worry. Task engagement incorporates the energetic arousal, motivation, and concentration scales and contrasts enthusiasm and interest with fatigue and
apathy. Distress encompasses negative moods and lack of confidence. Finally, Worry reflects the level of intrusive thoughts and other negative self-referent cognitions (Matthews et al., 2002). An extensive series of studies has revealed that the performance of vigilance tasks typically leads to a loss of engagement over time, accompanied by increasing distress (Grier et al., 2004; Helton, 2004; Helton, Dember, Warm, & Matthews, 2000; Helton et al., 2005; Matthews et al., 2002; Parsons et al., 2000; Szalma et al., 2004; 2006; Temple et al., 2000). Task engagement is a state factor that may index resource availability. Thus, a second goal for this study was to test the possibility that observers’ levels of task engagement following performance of the short battery would serve as a useful predictor of later vigilance performance.
Chapter 2

Method

Participants. One hundred and eighty seven introductory psychology students (114 females, 73 males) from the University of Cincinnati served as observers to fulfill a course requirement. They ranged in age between 18-40 years with a mean of 20 years. All participants were right-handed, had normal or corrected-to-normal vision, and were fluent in English. In addition, to minimize factors that could have uncontrolled effects on CBFV and vigilance performance (Davies & Parasuraman, 1982; Stroobant & Vingerhoets, 2000) observers were required to have no history of epilepsy, to not be taking psychoactive medications, and to refrain from caffeine and tobacco products for two hours before participating in the experiment.

Design. Experimental sessions were composed of three phases including an acclimation phase, an initial performance phase featuring a short battery of tasks, and a final vigilance performance phase. Cerebral blood flow velocity in the right and left medial cerebral arteries was recorded continuously during all phases of the experiment as described below. Task Engagement, Distress, and Worry were measured by the DSSQ.

Short Battery. The short battery was composed of three tasks: compensatory tracking, working memory, and line discrimination, all of which were presented on an 18 in video display terminal (VDT) mounted at eye level on a table 1 meter from the seated observer. Each task in the battery lasted for 2 min with a 2-min inter-task interval. The order of presentation of the battery components was varied at random for each observer.

In the tracking task, observers were required to use a joystick (Microsoft Sidewinder Precision 2) to keep a white crossbar (luminance = 47.71 cd/m² measured by a Minolta LS-100 Luminance Meter) centered on a gray vertical bar (luminance = 0.53 cd/m²) between two
reference points (luminance = 10.78 cd/m²) that were separated by 40 mm in the middle of the VDT (luminance = 0.03 cd/m²; resolution = 1024 x 768 pixels, refresh rate = 80 Hz). The tracking display, which was taken from Ungar (2005), is illustrated in Figure 1.

![Figure 1](image_url)  
**Figure 1.** The short battery tracking display.

The working memory task was based upon one developed by Turner and Engle (1989) and modified by Matthews et al. (1999) to impose a high degree of time pressure. The task was composed of 24 problems. Each problem had an arithmetic and word recall component. The arithmetic component was a simple calculation such as “(7 + 4) – 2 = 5.” observers were required to press a computer spacebar if the answer was correct and to do nothing if it was incorrect. A high frequency concrete noun (e.g., soldier) was printed in capital letters above the calculation component. Each problem was presented for 1.8 sec with an inter-item interval of 0.2 sec. After each set of six items, participants were prompted to type, in correct order, either the six initial letters or the six last letters of the nouns they encountered in that set of six. Observers had 15 sec to complete the typing following each set of six problems. Examples of correct and incorrect arithmetic answers and the complete list of the nouns employed are presented in Appendix A.

The line task was adapted from Matthews, Davies, and Holley (1993). Observers viewed pairs of horizontal (1 mm thick) lines separated by 25 mm. Stimuli were presented for 300 msec at a rate of one/sec. The base length of the lines was 84 mm but to increase task demand, line length varied randomly during presentation from 74 mm to 94 mm giving the lines a flickering appearance. Critical items for detection, which occurred 25 % of the time, were cases in which the
base length of both lines was 20% longer that that of the usual non-target items.

**Vigilance Task.** The vigilance task was adapted from Hitchcock et al. (2003). Observers monitored the simulated air-traffic control display illustrated in Figure 2.

![Figure 2. The vigilance task display. A collision course is illustrated on the left and a safe course on the right.](image)

The display consisted of a “city” (a solid red circle 10.5 mm in diameter luminance = 24.06 cd/m²) banded by a thin white border (.75 mm thick x 12 mm in diameter) and ringed by three circular white (luminance = 133.2 cd/m²) “outer markers” (.75 mm thick; 28mm, 53mm, and 83mm in diameter, respectively) with light gray in between (luminance = 110.6 cd/m²), and two “jet aircraft” represented by two light gray 1mm x 25 mm lines (luminance = 103.37 cd/m²) all of which were presented on a gray background (luminance = 81.54 cd/m²). The Michaelson contrast ratio [(maximum luminance –minimum luminance)/ (maximum luminance + minimum luminance)] x 100; Coren, Ward, & Enns, 2004] of the aircraft to their light gray background was 3.38%. The aircraft were equidistant from the “city” and approached it from opposite headings, either from northwest to southeast or from northeast to southwest. Within each of the two headings, one of the aircraft was vectored toward the center of the city. The flight path of the other aircraft was parallel to but displaced to the left or right of its cohort so that it would pass on a tangent to the “city.” The eight permutations of flight headings were presented randomly throughout the vigil and constituted neutral (safe) situations requiring no overt responses from the
observers. Critical signals for detection (emergency events) were cases in which the two aircraft in either the northwest/southeast or the northeast/southwest headings were aligned on a potential collision course over the center of the “city.” The display was updated 30 times/min with a dwell time of 300 msec. The task, which lasted for 36 min, was divided into four continuous nine min periods. Nine critical signals were presented on a random schedule during each watchkeeping period (signal probability = 0.03). Observers indicated their detection of critical signals by pressing the spacebar on a computer keyboard.

_Cerebral blood flow velocity measurement._ Cerebral blood flow velocity (CBFV) recordings were secured from a Nicolet Companion III Transcranial Doppler unit. To enable recording of hemovelocties, an observer wore two 2-Mhz ultrasound transducers embedded in an adjustable plastic bracket secured about the head and located dorsal and immediately proximal to the zygomatic arch along the temporal bone. To enhance the blood flow signal, a small amount of ultrasound gel (Aquasonic- 100) was placed between the transducers and the observer’s skin. The MCA was monitored at depths of 50 mm to 58 mm (distance between the transducer on the skin to the sample volume). Time-averaged blood flow velocities were updated by the TCD unit every 5 secs and displayed on the unit’s monitor. These values were retained by the unit for subsequent computer scoring. An illustration of an observer wearing the TCD headband is presented in Figure 3. The TCD equipment was located in an adjacent chamber out of view of the observer.

_Figure 3._ An observer wearing the TCD headpiece with transducers.
**Procedure.** Observers were tested individually in an 8.5 x 9 x 14 ft windowless, dimly lit (ambient illumination = 1.83 cd/m²), internal laboratory room. Illumination in the testing room was provided by a 25 w bulb mounted in a parabolic reflector affixed to the ceiling behind the seated observer and situated to minimize glare on the VDT. Upon arrival for the experiment, observers completed an informed consent form (see Appendix B), the inclusion criterion check list (see Appendix C), and a pre-test version of the DSSQ (see Appendix D). In addition, they were acclimated to the TCD recording procedure during a 2-min resting baseline in which they were asked to relax while gazing at the VDT which was blank. All subsequent CBFV scores were expressed as a proportion of the mean resting baseline value (Stroobant & Vingerhoets, 2000; Warm & Parasuraman, 2007). For each participant, the scores expressed in this way for any given component of the short battery were based upon an average of the 2-min exposure to that component. For the vigilance task, the scores for any 9-min period of watch were based upon the average for that period. After this introductory phase, observers completed the short battery and a post-test version of the DSSQ based on their experience with the short battery. Immediately after completing the DSSQ, observers were given a four-min practice period with the vigil in which signal probability was identical to that employed in the main vigil, and then performed the main vigil. Observers were not afforded a rest break between the practice and the main vigil. Following the completion of the main vigil, the TCD headband was removed and observers completed a second post-test version of the DSSQ in which the focus was their experience in the vigil. The post-test version of the DSSQ is presented in Appendix E. For the purpose of this investigation, pre-test and post-test DSSQ scores for Task Engagement, Distress, and Worry were calculated using standardized regression weights from a large normative sample as outlined by Matthews et al. (2002). Distributions of sample factor scores may be compared to the mean of 0 and SD of 1 in
the normative sample. Observers were required to surrender their watches, cell phones, pagers, and personal planners upon arriving for the experiment and had no knowledge of the length of the vigil other than the entire experimental session would not exceed three hours.
Chapter 3
Results

Manipulation Checks

Several analyses were conducted to ensure that the tasks elicited the expected behavioral and CBFV responses that could be used for later prediction of vigilance performance. These included (1) comparisons of the post-test DSSQ scores on the short battery and on the vigilance task with pre-test scores on these tasks, (2) checks to verify that short battery CBFV scores were appropriately lateralized, and (3) checks to verify that performance on the vigilance task and the CBFV scores on that task declined significantly over time.

*DSSQ scores.* Mean pre-test scores for each dimension of the DSSQ are presented in Table 1 along with mean post-test scores on these dimensions following the short battery and the main vigil. For each dimension, the table also includes mean post-pre difference scores (Δ’s).

Table 1.
Mean pre-test and post-test short battery/vigilance scores on the DSSQ.

<table>
<thead>
<tr>
<th></th>
<th>Pre-DSSQ</th>
<th>Post-Battery DSSQ</th>
<th>Post-Vigil DSSQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Worry</td>
<td>Engagement</td>
<td>Distress</td>
</tr>
<tr>
<td>Mean</td>
<td>0.29</td>
<td>0.23</td>
<td>-0.32</td>
</tr>
<tr>
<td>Δ</td>
<td>-0.58</td>
<td>-0.02</td>
<td>1.44</td>
</tr>
</tbody>
</table>

The difference scores indicated that the levels of *worry* and *task engagement* were depressed relative to the initial baseline level following both performance phases while *distress* was elevated relative to its initial baseline level following both performance phases. Tests of significance (*t*) against a null hypothesis of zero-change using the Bonferroni correction with an alpha level of .05 indicated that all of the post-pre differences were statistically significant except the difference in *engagement* following the short battery, *t* (186) > 7 for all significant effects.
Short-battery CBFV scores. Mean left and right hemisphere CBFV scores and their associated standard errors are presented in Figure 4 for each task of the short battery.

Figure 4. Left and right hemisphere phasic CBFV response (% baseline) to the components of the short battery. (Lines = line length discrimination, WM = working memory). Error bars are standard errors.

A 3 x 2 (short battery task x hemisphere) repeated measures analysis of variance (ANOVA) of the data of Figure 4 revealed that there was a significant task main effect, $F(1.77, 254.38) = 17.91$, $p < .001$, and a significant task by hemisphere interaction, $F(1.89, 272.14) = 29.93$, $p < .001$. It is evident in the figure that CBFV responses to the battery components were lateralized; CBFV was greater in the right than in the left hemisphere with the line task, while the opposite was true in the case of the working memory task, $t > 3.00$, $p <.05$ in both cases. Hemispheric differences in the tracking task were not significant ($t <1$, $p >.05$). However, the trend for greater CBFV in the right than in the left hemisphere is consistent with an earlier finding by Stroobant and Vingerhoets (2000) who reported greater right hemisphere CBFV in a tracking task. In this and in all subsequent ANOVA’s employing repeated measures, Box’s epsilon was
used when appropriate to correct for violations of the sphericity assumption (Maxwell & Delaney, 2004). A summary of this and all subsequent ANOVA’s can be found in Appendix F.

**Vigilance performance.** Three different measures were secured from the vigilance data. They included the percentage of correct detections (hits), false alarms, and A’. The latter is a signal detection theory index of perceptual sensitivity that combines correct detections and false alarms and is independent of observers’ biases in responding (Macmillan & Creelman, 2005). Since performance efficiency in the vigilance task was the principal focus for this study, and since A’ has been shown to decline over time on watch in several other experiments (See et al., 1995), it was the principal index by which to gauge performance efficiency in this experiment. Mean percentages of correct detections for each period of watch in the vigilance task are plotted in Figure 5. It can be seen in the figure that the detection scores declined linearly over time. An ANOVA revealed that the temporal decline in detections was statistically significant, $F(2.40, 444.41) = 35.01, p < .001$. Additionally, false alarm responses increased significantly over time in the vigilance task from 0.6% in the first period to 1.2% in the fourth period, $F(1.93, 357.67) = 4.83, p < .01$.

![Figure 5](image-url)  
*Figure 5.* Mean percentages of correct detections as a function of periods of watch in the vigilance task. Error bars are standard errors.
Mean A’ scores across time on watch are displayed in Figure 6. Like the percentage of correct detections, the perceptual sensitivity scores also decreased linearly over time and the temporal decline was statistically significant, $F(2.79, 498.86) = 48.66, p < .01$. In this and all subsequent analyses the A’ scores were arcsine transformed to reduce negative skew.

![Graph showing A' scores](image)

*Figure 6.* Mean A’ scores as a function of periods of watch on the vigilance task Error bars are standard errors.

**CBFV and vigilance.** Cerebral blood flow velocities in the left and right hemispheres during performance of the vigilance task are displayed in Figure 7. A 2 x 4 (hemisphere x period) ANOVA revealed significant main effects for hemisphere, $F(1, 120) = 7.57, p < .01$ and periods of watch, $F(2.02, 242.01) = 11.93, p < .01$. The interaction between these factors was not significant, $p > .05$. It is evident in the figure that CBFV during the vigilance task was greater in the left than in the right hemisphere and that CBFV declined over time in a similar manner in both hemispheres.
Figure 7. CBFV in each cerebral hemisphere as a function of periods of watch. Error bars are standard errors.

Correlates of Vigilance Performance.

CBFV inter-correlations among the components of the short battery. Intra-hemispheric and inter-hemispheric correlations between CBFV response magnitudes for the three battery tasks are shown in Table 2.

Table 2.

**Intra- and inter-hemispheric CBFV correlations across the short battery tasks.**

<table>
<thead>
<tr>
<th></th>
<th>Line</th>
<th>LH WM</th>
<th>Tracking</th>
<th>RH Line</th>
<th>RH WM</th>
<th>RH Tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH</td>
<td>Line</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WM</td>
<td>.523**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tracking</td>
<td>.637*</td>
<td>.384**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH</td>
<td>Line</td>
<td>.490**</td>
<td>.306**</td>
<td>.256**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WM</td>
<td>.244**</td>
<td>.547**</td>
<td>.115</td>
<td>.538**</td>
<td>1.00</td>
</tr>
</tbody>
</table>
|       | Tracking | .374** | .341** | .389** | .668** | .549**      | 1.00

**p<.01

**
It is evident in the table that individual differences in the CBFV values associated with the short tasks were reliable across the different components of the task battery. A principal components analysis suggested that separate, but correlated ($r = 0.44$), measures of RH and LH CBFV could be distinguished. The mean LH and RH CBFV responses, averaged across the three component tasks of the battery, were calculated for use in subsequent analyses. These response indices were only weakly related to baseline CBFV (LH, $r = -.152, p < .05$; RH, $r = -.161, p < .05$). Baseline CBFV was not found to predict either subjective state or performance in this study.

The LH and RH CBFV response indices proved to be correlated with post-battery DSSQ task engagement (LH, $r = .172, p < .05$; RH, $r = .256, p < .01$).

**Univariate prediction across the vigil.** The CBFV and task engagement measures obtained during or after the short battery, respectively, were tested as predictors of subsequent vigilance performance. The correlations of the two CBFV measures and post-battery DSSQ task engagement with performance during the four periods of the vigilance task are shown in Table 3. Data for each of the three performance measures, correct detections, false alarms, and A’, are shown separately. It is clear in the table that higher task engagement was consistently related to a higher rate of correct detections, fewer false alarms, and higher perceptual sensitivity in each of the four task periods. CBFV scores in the two cerebral hemispheres were more closely associated with a lower rate of false alarms than with correct detections since more of the CBFV/period correlations were significant with the false alarm measure. However, high LH CBFV predicted more correct detections in the later part of the vigil and both LH and RH CBFV scores were significantly correlated with perceptual sensitivity in the later periods of the task.
Table 3.

*Correlations between three indices of vigilance performance and short battery CBFV and DSSQ*  
*Task Engagement scores across the 9-min task periods.*

<table>
<thead>
<tr>
<th></th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Correct Detections</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH CBFV</td>
<td>-.039</td>
<td>.067</td>
<td>.152*</td>
<td>.185*</td>
</tr>
<tr>
<td>RH CBFV</td>
<td>.076</td>
<td>.089</td>
<td>.080</td>
<td>.124</td>
</tr>
<tr>
<td>Engagement</td>
<td>.213**</td>
<td>.226**</td>
<td>.229**</td>
<td>.268**</td>
</tr>
<tr>
<td><strong>False Alarms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH CBFV</td>
<td>-.163*</td>
<td>-.138</td>
<td>-.071</td>
<td>-.039</td>
</tr>
<tr>
<td>RH CBFV</td>
<td>-.188*</td>
<td>-.159</td>
<td>-.167*</td>
<td>-.179*</td>
</tr>
<tr>
<td>Engagement</td>
<td>-.211**</td>
<td>-.200**</td>
<td>-.191**</td>
<td>-.057</td>
</tr>
<tr>
<td><strong>A’</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH CBFV</td>
<td>.015</td>
<td>.115</td>
<td>.158*</td>
<td>.184*</td>
</tr>
<tr>
<td>RH CBFV</td>
<td>.131</td>
<td>.176*</td>
<td>.177*</td>
<td>.180*</td>
</tr>
<tr>
<td>Engagement</td>
<td>.209**</td>
<td>.258**</td>
<td>.197**</td>
<td>.305**</td>
</tr>
</tbody>
</table>

*p<.05, **p<.01

Multivariate prediction of Period 4 Performance. Since vigilance performance is most vulnerable to impairment towards the end of the period of work, a key operational issue is the prediction from the short battery measures to performance at the end of the vigil. Such a prediction could be accomplished via multiple regression analysis. However, since the observers’ A’ scores in the fourth period were related those in the first period, r = .223, p<.01, it was first necessary to establish that any contribution made by the short battery measures to final period performance accounted for sources of variance beyond that accounted for by their performance in the initial period of watch. Toward that end, partial correlations between A’ at period 4 and the predictors, controlling for A’ at period 1, were computed. A’ at period 4 remained significantly correlated with engagement (r = .255, p < .01), LH CBFV (r = .225, p < .01), and RH CBFV (r = .180, p < .05), thus indicating that period 4 predictions from the short battery measures were independent of period 1 performance alone.
A hierarchical regression analysis was conducted to test how much of the total variance in A’ during period 4 could be predicted from the two CBFV measures and the DSSQ engagement measure derived from the short battery. The DSSQ worry and distress measures secured from the short battery were included in the analysis to determine if these state measures also contributed to the regression model. The two CBFV measures were entered into the regression at the first step, followed by the three DSSQ factors at the second step. The final equation attained significance, $F(5, 139) = 4.08, p < .01$. Table 4 verifies that both steps added significantly to the variance explained. Standardized beta coefficients were .127 and .120 for the left and right hemisphere CBFV scores, respectively. Those for the state measures of engagement, distress, and worry were .266, -.092, and -.060, respectively, indicating that the state measure of engagement contributed more substantially to the multiple regression model than the worry and distress measures.

Table 4.

**Summary statistics for the multiple regression of CBFV and DSSQ short battery scores on A’ during the fourth period of the vigilance task.**

<table>
<thead>
<tr>
<th>Step</th>
<th>Predictors</th>
<th>R</th>
<th>df</th>
<th>Adjusted R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LH and RH CBFV</td>
<td>.212*</td>
<td>2, 144</td>
<td>.031*</td>
</tr>
<tr>
<td>2</td>
<td>Engagement, Distress, and Worry</td>
<td>.358**</td>
<td>5, 139</td>
<td>.097*</td>
</tr>
</tbody>
</table>

*p<.05, **p<.01

**Specificity of prediction from CBFV measures.** The resource model implies that tasks drawing on different component processes may nevertheless draw on common resources. If so, there should be little systematic difference between the predictive power of the CBFV responses to the component tasks of the short battery. By contrast, if CBFV response is linked to specific
component processes, then it would be expected that vigilance would be most strongly predicted by CBFV response to the line discrimination task, the task in the battery that matched the processing requirements of the vigilance task most closely. Table 5 shows the correlations between LH and RH CBFV responses to the individual component tasks and fourth period A’ scores. Clearly, the line task of the short battery was not the only component of that battery to predict period 4 performance in the vigilance task. Left hemisphere CBFV responses to the line and tracking tasks predicted A’ performance in period 4 while the RH CBFV response to the working memory task did so as well.

Table 5.

*Correlations between CBFV measures for the three component tasks of the short battery and A’ during the fourth period of the vigilance task.*

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<thead>
<tr>
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<tr>
<td></td>
<td>Lines</td>
<td>Working Memory</td>
<td>Tracking</td>
<td>Lines</td>
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<tr>
<td><em>r</em></td>
<td>.186*</td>
<td>.091</td>
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<td>.069</td>
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*p < .05
Chapter 4

Discussion

The present study was prompted by an important practical concern – the need to develop effective procedures by which to select individuals for tasks in which sustained attention or vigilance functions play a key role. A unique feature of this investigation, derived from a resource theory of vigilance (Davies & Parasuraman, 1982; Parasuraman, 1979; Parasuraman & Davies, 1977; Parasuraman, Warm, & Dember, 1987; Warm & Dember, 1998), was the use of physiological (left and right CBFV) and subjective state (task engagement) measures secured from a battery of demanding and stressful information-processing tasks to predict vigilance performance. Manipulation checks showed that the task procedures provided a suitable platform in that regard. The short task battery elicited increased subjective distress relative to baseline as indexed by the DSSQ, a result that accords with those obtained with this instrument in several other high information-processing demand tasks (Matthews et al., 2000). Also consistent with prior DSSQ findings, the vigilance task was associated with increased distress and a decline in task engagement, corresponding to a state of fatigue (Grier et al., 2004; Helton, 2004; Helton, Dember, Warm, & Matthews, 2000; Helton et al., 2005; Matthews et al., 2002; Parsons et al., 2000; Szalma et al., 2004; 2006; Temple et al., 2000). Moreover, as in previous studies, the vigilance task produced a decline in performance that was paralleled by a bilateral decline in CBFV (Warm, & Parasuraman, 2007) and individual differences in CBFV were found to be reliable and meaningfully inter-related across tasks and hemispheres. In addition, CBFV responses to the short battery were appropriately lateralized. As might be anticipated from previous hemispheric findings (Hellige, 1993), higher levels of CBFV were found in the left as compared to the right hemisphere for a linguistic working memory task, while CBFV was higher
in the right than in the left hemisphere with a spatial discrimination task involving line length. In regard to manipulation checks for task demand and stress, the decrease in worry reported by observers after both the short battery and the vigilance task might seem anomalous. However, a decline in worry has been found in many other studies using the DSSQ as a stress state index and most likely reflects observers’ increased comfort stemming from enhanced familiarity with the task (Matthews et al., 2002).

The results of this study support a general strategy of assessing observers’ responses to a cognitive challenge, which may provide both physiological and subjective predictors of subsequent vigilance performance. Modest but significant univariate correlations ranging from .176 to .305 were obtained between fourth period perceptual sensitivity on the vigilance task and the CBFV and task engagement measures on the short battery. The level of prediction was improved when a multiple correlation model was employed. Specifically, the multiple $R$ using the CBFV and DSSQ state measures in conjunction with perceptual sensitivity in the fourth period on the vigilance task was .358. Two aspects of these correlational data are important. Although also modest, accounting for only 9.7 percent of the variance on the vigilance task when adjusted for shrinkage, the multiple $R$ is sufficiently large to be practically useful for selection purposes.

Koelega (1992) and Rosenthal and Rubin (1982) have indicated that accounting for 4 percent of the variance on a target performance task might lead to an increase in job success rate of 40 to 60 percent. As Rose et al. (2002) have noted, this level of explained variation is meaningful given that vigilance failures in situations such as air-traffic control, baggage screening, and medical monitoring can be extremely costly in terms of public safety and health. Moreover, the multiple $R$ predicted perceptual sensitivity in the final period of the vigilance task even with first-period performance statistically controlled, suggesting that over and above the initial level of
performance, the multiple measure may be useful in predicting which observers are capable of maintaining vigilance during late portions in the watchkeeping assignment when performance deficiencies are most likely to occur. Additionally, it should be noted that the standardized beta values in the multiple regression model indicated that task engagement, the state measure initially hypothesized to relate to vigilance, contributed more substantially to the variance explained than did the additional state measures of distress and worry that index qualitatively different features of the stress response to the task.

Along with their practical implications, the results of the present study also have meaning on a theoretical level. As hypothesized from the resource model of vigilance, subjective task engagement and phasic CBFV responses to the short task battery correlated significantly with subsequent vigilance performance. Accordingly, as Matthews and Deary (1998) have suggested, task engagement and CBFV increments may both reflect a common resource pool for “energization” of information-processing. Indeed, task engagement was positively correlated with CBFV, an outcome that is consistent with the view that subjective state depends on both neurophysiological and cognitive factors (Fairclough & Venables, 2006; Matthews, 2001).

The resource model is also supported by the intercorrelation of the CBFV responses to three tasks of differing information-processing characteristics, suggesting that CBFV is driven by overall demand, rather than any specific processing component. A similar conclusion is supported by the observation that the ability of component-task CBFV responses to the screening battery to predict vigilance does not appear to be limited to any one of the tasks.

While the present results indicate that both left and right CBFV responses to the short battery contributed to the multiple regression model in predicting subsequent vigilance performance, two aspects of the data indicate that further study of the role of hemispheric
specialization in resources may be needed. The finding that the overall level of CBFV on the vigilance task was greater in the left than in the right cerebral hemisphere is inconsistent with previous reports of CBFV in vigilance wherein CBFV was found to be greater in the right than in the left hemisphere (Shaw, 2006; Warm & Parasuraman, 2007). The present study was the initial experiment in which vigilance performance was immediately preceded by performance on a battery of information-processing tasks that involved differing laterality effects. The role of task precedence in driving CBFV responses in vigilance would appear to warrant further investigation. Moreover, in regard to the specificity of prediction from CBFV measures, the finding that left hemisphere and right hemisphere CBFV responses to the line and working memory components of the short battery, respectively, predicted fourth period vigilance performance is not consistent with the general notion that visuospatial tasks are controlled in the right hemisphere and verbal tasks in the left. However, as Hellige (1993) has noted, even relatively simple tasks require the coordination of a number of information-processing subsystems and the magnitude of hemispheric asymmetry is often different from subsystem to subsystem precluding overly simple claims about hemispheric superiority for an entire task. The role of such subsystems in the outcome of the present study is another issue that warrants further investigation.
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Appendix A:

Examples of correct and incorrect arithmetic answers and the complete list of the nouns employed are presented in Appendix A.
List of Working Memory Short Battery Nouns

1. LIGHT
2. MERCHANT
3. MARBLE
4. SOLDIER
5. PARLOUR
6. FATHER
7. VERSE
8. NAIL
9. ROAD
10. LOG
11. WING
12. JUNGLE
13. ICE
14. PEASANT
15. STAR
16. MAN
17. PATH
18. NEEDLE
19. BASKET
20. ORBIT
21. MUSCLE
22. PLANE
23. PILOT
24. BABY

Examples of Correct and Incorrect Math Problems

Correct: 

(2 + 4) − 2 = 6
3 + (2 − 1) = 4
(4 + 4) − 3 = 5
5 − (2 + 1) = 2

Incorrect:

6 − (2 + 3) = 3
(5 - 4) + 2 = 4
1 + (3 - 2) = 1
(4+2) − 5 = 4
Appendix B:

Informed consent form.
TITLE OF STUDY: Diagnostic Methods for Predicting Performance Impairment During A Sustained Attention Task

PRINCIPAL INVESTIGATOR: Gerald Matthews PHONE: (513) 556-0954

1. INTRODUCTION:
Before agreeing to participate in this study, it is important that the following explanation of the proposed procedures be read and understood. It describes in words that can be understood by a lay person, the purpose, procedures, benefits, risks and discomforts of the study and the precautions that will be taken. It also describes the alternatives available and the right to withdraw from the study at any time. It is important to understand that no guarantee or assurance can be made as to the results of the study. It is also understood that failure to complete the session will in no way affect the course grade or class credit. Alternatives to research participation are described in the memo on "Research Participation Requirement" distributed to all introductory psychology students.

2. OBJECTIVES OF THE STUDY:
"I, ______________________, voluntarily consent to participate in a research study, the purpose of which is to investigate measures that may predict how well a person performs on a simulated air traffic control task. The study also aims to investigate subjective and physiological reactions to performing mentally demanding tasks. You will be one of approximately 200 participants taking part in this study.

3. PROCEDURES:
The present study will last approximately 110 minutes, and, in any case, no longer than 120 minutes. Initially, you will complete a short questionnaire that assesses your personality. You will then perform a short series of computerized psychological tasks requiring signal detection and manual control. Your speed and accuracy of performance will be recorded by the computer. You will also perform a longer simulated air traffic control task, during which your speed and accuracy of performance will also be recorded. Before and after performing these tasks, you will complete questionnaires that assess your feelings about the task, and how much awareness you had of the task situation. You will also be asked to provide saliva samples by chewing on a piece of cotton wool for about 2 minutes. These samples will be analyzed for cortisol, a hormone that may indicate levels of stress. These samples will be destroyed following this analysis. In addition, the rate of bloodflow in your cerebral arteries will be recorded during task performance. This is a painless, harmless and non-invasive procedure, that measures rate of bloodflow by analyzing the Doppler shift of an ultrasound signal. It requires that two transducers will be placed on your head, together with conducting gel.

4. EXCLUSION: You will not be able to participate in the study if any of the following applying to you:
(1) impairment of vision (corrected vision is acceptable);
(2) physical inability to perform psychological tasks using a keyboard and mouse;
(3) lack of fluency in English;
(4) taking psychoactive medication;
(5) taking medication containing corticosteroids;
(6) have a history of past or current epilepsy;

Prior to participation in the study you are asked to confirm that (1) you have refrained from alcohol use for 24 hours prior to participation, and (2) you have refrained from substantial meals, drinks containing citrus, caffeinated products, tobacco use and vigorous physical exercise for 2 hours prior to participation.
4. BENEFITS:
If you are participating in this study to satisfy a requirement for an introductory psychology class, participation will earn 3 hours of experimental credit towards the completion of this course (you will earn one hour of experimental credit for each hour of participation). All other requirements pertaining to the completion of this course must be discussed with the instructor. If you are not a student in need of experimental credit, you are not likely to receive any direct immediate benefit as a result of this research. However, the findings of this project may contribute to our knowledge of human performance.

5. RISKS, DISCOMFORTS, AND PRECAUTIONS:
There are no major risks or discomforts associated with this study. This is a behavioral research project and thus involves minimal risk. The tasks have been used in previous psychological studies, and no harmful effects have ever been reported as a result of using these tasks as part of a research study. The tasks are somewhat mentally demanding, and you may experience some minor discomforts by being asked to complete them (i.e., eye strain, postural discomfort from sitting, fatigue etc.). However, the risks for any physical or psychological harm are minimal.

In the event that you become ill or injured from participating in this research study, emergency medical care will be provided to you. The University of Cincinnati will decide on a case by case basis whether to reimburse you for your out of pocket health care expenses. No other compensation is available. You understand that the University of Cincinnati follows a policy of making all decisions concerning compensation and medical treatment for injuries occurring during or caused by participation in biomedical or behavioral research on an individual basis. If you believe that you have been injured as a result of research, you will contact Dr. Gerald Matthews at (513) 556-0954, or, if he is unavailable, Dr. Joel S. Warm at (513) 556-5533. You may also contact Dr. Margaret Miller, Chair of the Institutional Review Board - Social and Behavioral Sciences, at (513) 558-5784.

6. ALTERNATIVES:
You understand that if you do not finish this session, this will in no way affect your course grade or class credit.

7. CONFIDENTIALITY OF RECORDS:
Confidentiality will be protected as follows. Participants in this study will not be individually identifiable. No information regarding the name, social security number, or any other identifying information will be gathered from participants. No audio or video tapes of participants will be made. Each subject will be allocated an arbitrary identifier, beginning with 1 for the first subject, and continuing sequentially until all subjects have been run. These subject identifiers will be discarded after data have been entered into computer files, to protect confidentiality.

Agents of the University of Cincinnati will be allowed to inspect sections of the research records related to this study. The data from the study may be published; however, you will not be identified by name. It should be noted that representatives of the U.S. Army Medical Research and Materiel Command are eligible to review research records as a part of their responsibility to protect human subjects in research.

8. AVAILABILITY OF INFORMATION:
You understand that if you have any questions concerning this study, you may contact Dr. Gerald Matthews at (513) 556-0954, or, if he is unavailable, Dr. Joel S. Warm at (513) 556-5533. You also understand that if you wish to receive a summary of the results of this study, you must furnish a stamped, self-addressed envelope. If you have any questions about your rights as a research participant, you may call Dr. Margaret Miller, Chair of the Institutional Review Board - Social and Behavioral Sciences, at (513) 558-5784.

9. RIGHT TO WITHDRAW:
You understand that your participation is strictly voluntary and you may refuse to participate, or discontinue your participation AT ANY TIME, without penalty or loss of benefits to which you are otherwise entitled. You also understand that the investigator has the right to withdraw you from the study
AT ANY TIME. You also understand that your withdrawal from the study may be for reasons related solely to you (i.e., not following study-related direction for the investigator, a serious adverse reaction).

10. SIGNATURES:
Nothing in this consent form waives any legal right you may have nor does it release the investigator, the sponsor, the institution, or its agents from liability for negligence.
"I, the undersigned, have read the above explanations and given consent to my voluntary participation in the study, 'Diagnostic Methods for Predicting Performance Impairment Associated with Combat Stress'."
(After signing this form, you will be provided with a copy.)

_________________________________ ________________
Signature of Participant Date

_________________________________ ________________
Signature of Investigator Date

This study has been reviewed and approved by the Committee on Human Research of the University of Cincinnati.
Appendix C:

Inclusion criterion checklist.
Checklist

Sub # ________  
Date ________  
Time ________

Task Order ________

Evaluate whether meet criteria

____ Are you right-handed?  
____ Are you between the ages of 18-40?  
____ Are you currently taking any psychoactive medication?  
____ Do you have a history of epilepsy?  
____ Are you fluent in English?  
____ Do you have 20/20 vision or corrected vision?

Evaluate adherence to requirements

____ Did you ingest alcohol in the last 24 hours?  
____ Did you ingest drinks containing citrus or any caffeinated products?  
____ Have you used any tobacco products in the last 2 hrs?  
____ Have you reframed from vigorous physical activity in the last 2 hrs?  
____ Have you had a substantial meal in the last 2hrs?

Comments:  
______________________________________________________________________________  
______________________________________________________________________________  
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Appendix D:

A copy of the pre-test version of the DSSQ.
Appendix E:

A copy of the post-test versions of the DSSQ.
Appendix F:

Summaries of all ANOVA’s.
A 3x2 repeated measures ANOVA of hemisphere and the short battery.

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*Values are taken directly from SPSS printout. Note: SPSS carries calculations out to many decimal places. For brevity, values are rounded in the table to two decimal places.
Table C.2

ANOVA of correct detections across the four periods of the vigilance task.

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*Values are taken directly from SPSS printout. Note: SPSS carries calculations out to many decimal places. For brevity, values are rounded in the table to two decimal places.

Table C3.

ANOVA of false alarms across the four periods of the vigilance task.

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</tr>
<tr>
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<td>Huynh-Feldt</td>
<td>361.38</td>
<td>3.38</td>
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</tr>
<tr>
<td></td>
<td>Lower-bound</td>
<td>185.00</td>
<td>6.60</td>
<td></td>
</tr>
</tbody>
</table>

*Values are taken directly from SPSS printout. Note: SPSS carries calculations out to many decimal places. For brevity, values are rounded in the table to two decimal places.
Table C4.

ANOVA of arcsine transformed A’ across the four periods of the vigilance task.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERIOD Sphericity Assumed</td>
<td>3.00</td>
<td>0.81</td>
<td>48.66</td>
<td>0.00</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
<td>2.79</td>
<td>0.88</td>
<td>48.66</td>
<td>0.00</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>2.84</td>
<td>0.86</td>
<td>48.66</td>
<td>0.00</td>
</tr>
<tr>
<td>Lower-bound</td>
<td>1.00</td>
<td>2.44</td>
<td>48.66</td>
<td>0.00</td>
</tr>
<tr>
<td>Error(PERIOD) Sphericity Assumed</td>
<td>537.00</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
<td>498.86</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>507.55</td>
<td>0.02</td>
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<td></td>
</tr>
<tr>
<td>Lower-bound</td>
<td>179.00</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Values are taken directly from SPSS printout. Note: SPSS carries calculations out to many decimal places. For brevity, values are rounded in the table to two decimal places.
Table C5.

A 2x4 repeated measures ANOVA of hemisphere and periods of the vigilance task.

<table>
<thead>
<tr>
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<th>MS</th>
<th>F</th>
<th>Sig.</th>
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<td>7.57</td>
<td>0.01</td>
</tr>
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<td>1.00</td>
<td>1429.12</td>
<td>7.57</td>
<td>0.01</td>
</tr>
<tr>
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<td>Huynh-Feldt</td>
<td>1.00</td>
<td>1429.12</td>
<td>7.57</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Lower-bound</td>
<td>1.00</td>
<td>1429.12</td>
<td>7.57</td>
<td>0.01</td>
</tr>
<tr>
<td>Error(HEMISPHE)</td>
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<td>120.00</td>
<td>188.70</td>
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<tr>
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<td>Greenhouse-Geisser</td>
<td>120.00</td>
<td>188.70</td>
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<tr>
<td></td>
<td>Huynh-Feldt</td>
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<td>188.70</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Lower-bound</td>
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<td>188.70</td>
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<tr>
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<td>11.93</td>
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<tr>
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<tr>
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<tr>
<td></td>
<td>Huynh-Feldt</td>
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</tr>
<tr>
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<td>Lower-bound</td>
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<td>49.53</td>
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</tr>
<tr>
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<tr>
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<tr>
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<td>2.25</td>
<td>20.20</td>
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<tr>
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<td>1.96</td>
<td>0.16</td>
</tr>
<tr>
<td>Error(HEMISPHE*PERIOD)</td>
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<td>360.00</td>
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<td>265.14</td>
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<td>Huynh-Feldt</td>
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<td>Lower-bound</td>
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<td>23.24</td>
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</tbody>
</table>

*Values are taken directly from SPSS printout. Note: SPSS carries calculations out to many decimal places. For brevity, values are rounded in the table to two decimal places.