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SENSORY AND TEMPORAL DETERMINANTS OF WORKLOAD AND STRESS IN SUSTAINED ATTENTION

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ABSTRACT

The expanded use of automation has altered the role of operators in many work settings from active controllers to executive-monitors who must attend to displays and take action only in the event of imminent problems (Sheridan, 1987). There is substantial evidence that monitoring or vigilance tasks impose high workloads on operators and that they find such tasks to be stressful. Overall workload scores in vigilance typically fall in the mid to upper range of the NASA Task Load Index (NASA-TLX), a standard instrument for measuring perceived mental workload, and increase linearly over time (Warm, Dember, & Hancock, 1996). Moreover, observers report being less attentive, and more bored, strained, irritated, and fatigued at the end of a vigil than prior to its start (Warm, 1993). The workload and stress of monitoring tasks is a concern for human factors specialists, given the negative impact of such effects on worker health/productivity (Nickerson, 1992).

To date, research on the workload of sustained attention has been conducted exclusively with visual tasks. However, monitoring tasks can also be performed in the auditory modality, and the sensory modality of signals is not a matter of indifference where vigilance is concerned. The speed and accuracy of signal detections is greater for auditory than visual signals and the vigilance decrement, the typical decline in detection efficiency over time in vigilance performance, is less pronounced in acoustic than visual tasks. (Warm & Jerison, 1984). These performance effects suggest the need for an examination of the potential contribution to workload made by the sensory channel to be monitored: auditory presentations may not only bolster signal detection but may also lower workload in comparison to analogous visual presentations. Such an examination,

in terms of overall workload and the growth of workload over time, was one goal for the present study.

While sensory issues have been neglected in regard to the workload of sustained attention, they have not been overlooked with respect to the subjective stress associated with monitoring performance: auditory tasks are less fatiguing than their visual counterparts (Galinsky, Rosa, Warm, & Dember, 1993). However, unlike the case with performance and workload, studies of task-induced subjective stress in vigilance have not examined the rate of gain of stress over time. Such an examination in the auditory and visual channels was a second goal for this experiment.

Two sensory modalities (auditory and visual) were combined factorially with four vigil durations (10, 20, 30, or 40 min). Thirty-two observers (16 men and 16 women) were assigned at random to each of eight independent groups resulting from the combinations of sensory modality and vigil duration. Performance data from the 20-min, 30-min, and 40-min conditions were based only upon the final 10-min of the vigil.

In order to assess the effects of audio-visual channels *per se* on performance, workload, and stress, the vigilance tasks used in this study featured temporal discriminations because such discriminations correlate highly in audition and vision (Dember & Warm, 1979). Observers monitoring the visual display viewed repetitive presentations of a horizontal white bar that appeared against a gray background on a VDT. Neutral events were flashes lasting 247.5 ms; critical signals for detection were briefer flashes (125 ms). Observers monitoring the auditory display listened to 247.5 ms bursts of white noise presented binaurally via headphones under conditions in which the loudness of the noise was matched to the brightness of the visual stimulus by means of a cross-modality matching procedure (Stevens, 1959). In this case, critical signals were brief 200 ms noise bursts. The duration disparity in defining auditory and visual critical signals was necessary to compensate for the fact that such discriminations are more acute in the auditory modality (Dember & Warm, 1979). Pilot work insured that the auditory and visual discriminations used in this experiment were equated for discrimination difficulty under alerted conditions.

Perceived mental workload was measured by the NASA-TLX, which was administered immediately after the vigil. Perceived stress was measured using the Dundee Stress State Questionnaire (DSSQ), a 77-item multidimensional instrument for assessing transient states associated with mood, arousal, and fatigue (Matthews, Joyner, Gilliland, Huggins, & Falconer, 1999). It consists of ten subscales measuring *Task Engagement* (Energetic Arousal, Motivation, Concentration), *Distress* (Tense Arousal, Hedonic Tone, Confidence and Control), and *Worry* (Self-Focused Attention, Self-Esteem, Task-Related Cognitive Interference, and Task-Irrelevant Cognitive Interference). The DSSQ was administered in two parts: a pre-vigil questionnaire completed prior to the practice session and a post-vigil questionnaire completed after the vigil. To avoid possible testing bias, half the observers (equated for sex) in each sensory modality-vigil duration group was administered the TLX, while the remaining half completed the DSSQ.

Performance efficiency, in terms of the percentage of correct detections, declined over time and signal detectability was higher for auditory than for visual signals. These effects occurred even though the tasks were carefully equated for discrimination difficulty. Therefore, the modality differences are likely due to factors such as the asthenopia and musculoskeletal fatigue which have been found previously to be associated with the use of video display terminals (Galinsky et al., 1993).

While the overall workload scores on the TLX were substantial, workload was unrelated to the sensory modality of signals. Thus, workload was dissociated from performance. Such dissociations may be based upon Yeh and Wickens' (1988) finding that perceived mental workload is driven to a considerable extent by the demand imposed on working memory. Given that the audio-visual tasks both required difficulty-equated absolute judgments, the absence of modality effects on workload may reflect the similar working memory demands of these tasks. Global scores on the TLX were stable over time. However, scores on the Frustration subscale of the workload instrument increased linearly with time on watch, an effect which may be linked to observers' inability to summon processing resources (Yeh & Wickens, 1988), which, according to the resource model of vigilance, are depleted over the course of a vigil (Parasuaman, Warm, & Dember, 1987).

Results with the DSSQ confirmed earlier findings indicating that vigilance tasks are stressful and indicated that the stress of sustained attention is multidimensional in character and tied to both the sensory modality of signals and time on watch. Observers in the visual task were found to be uniformly less motivated and happy during the vigil than those in the auditory task. In addition, Confidence and Control decreased while Tension and Task-Relevant and Task-Irrelevant Cognitive Interference increased with time on watch. In the case of the three latter dimensions, the sensory modality of signals served as a moderator variable for the effects of time; stress increased monotonically over the course of the vigil for visual signals but followed an inverted-U shaped function for auditory signals, rising during the early portion of the vigil and returning to baseline by the end of the session. Based upon the transactional model of stress proposed by Lazarus and Folkman (1984), these results may reflect different coping strategies in which observers in the auditory task, who were not burdened by the asthenopia and musculoskeletal fatigue associated with visual tasks, were more successful in their efforts to handle the stress of sustained attention.

Taken together with the TLX Frustration results, the DSSQ findings indicate that in order to minimize operator stress, display modality and time on task should be important considerations in the design of systems which include vigilance components.

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DEDICATION

For my wife, Missy, with love.

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CHAPTER I

Introduction

The Problem of Vigilance

Vigilance and Automation. Vigilance or sustained attention concerns the ability of observers to detect transient and infrequent signals over prolonged periods of time. That aspect of human performance is of considerable interest to human factors/ergonomic specialists because of the critical role that vigilance occupies in automated human-machine systems (Boff & Lincoln, 1988; Davies & Parasuraman, 1982; Howell, 1993; Koelega, 1992; Nachreiner & Hanecke, 1992; Parasuraman, 1986; Proctor & Van Zandt, 1994; Warm, 1993; Parasuraman, Warm, & Dember, 1987; Wickens, Gordon & Liu, 1998).

As Sheridan (1970; 1987) has noted, the utilization of automatic control and computing devices for the acquisition, processing, and storage of information has altered the role of the human operator in many work settings from that of active hands-on controller to a monitor-executive who must attend to displays and take action only in the event of imminent problems. Thus, operator vigilance is a key aspect of system function in a variety of activities, including military surveillance, air-traffic control and cockpit monitoring, seaboard navigation, robotic manufacturing, and industrial process and quality control (Satchell, 1993; Warm, 1984; 1993; Wickens, 1992). Vigilance is also a crucial element of performance efficiency in many medical settings including cytological screening, prodromal symptom monitoring, and the inspection of anesthesia gauges during surgery (Daly & Wilson, 1993; Gill; 1996; Paget, Lambert, & Sridhar, 1981; Weinger & Englund, 1990). Failure to notice untoward events (critical signals) in these settings can have serious consequences for worker productivity, public safety, and health (Warm, 1993).

Origins of Vigilance Research. The term "vigilance" was first employed in 1923 by Sir Henry Head to describe a state of maximum physiological and psychological readiness to react (Davies & Parasuraman, 1982;Warm, 1984). However, systematic laboratory research did not begin until 20 years later, when Norman Mackworth (1948; 1950/1961) was asked to address a practical problem that confronted the Royal Air Force during WWII. A major technological innovation of that time was the use of radio detection and ranging --radar-- by airborne reconnaissance observers to detect the presence of enemy submarines on the surface of the sea below. Although well trained and highly motivated, the airmen began to miss signals after only 30 min on watch. As a result, the U-boats could more easily sink British ships.

Mackworth attacked this problem experimentally by employing a simulated radar display called the *clock test*, consisting of a black pointer that moved along the circumference of a white blank-faced clock containing no scale markings or reference points. The pointer moved 0.3 inches to a new position once every second; the task of the observer was to respond to occasional "double jumps" of 0.6 inches. In Mackworth's experiments, *as in most of those that have followed*, observers were tested alone; the task was prolonged (two hours) and continuous; the signals to be detected were clearly perceptible when observers were alerted to them, but were not compelling changes in the operating environment; the signals appeared in a temporally unpredictable manner with low probability of occurrence; and observers' responses had no bearing on the probability of occurrence of critical signals.

Using the clock display in this way, Mackworth confirmed field-derived suspicions that the quality of sustained attention is fragile, waning quickly over time. Although the initial level of signal detections in his experiment was quite good -- signals were detected 85% of the time-- Mackworth found that detections declined by 10% after only 30 min on watch and continued to drop-off thereafter. This decline in efficiency with time on watch is known as the *vigilance decrement or the decrement function*. It has been confirmed repeatedly in many studies and is the most ubiquitous finding in research on sustained attention (Davies & Parasuraman, 1982; See, Howe, Warm, & Dember, 1995; Warm, 1984; 1993). The decrement function has been observed with experienced monitors, such as those employed in Mackworth's experiments, as well as in inexperienced monitors, and it has been observed in operational environments as well as in laboratory settings (Baker, 1962; Colquhoun, 1967; 1977; Pigeau, Angus, O'Neill, & Mack, 1995; Schmidke, 1976).

The Cost of Sustained Attention. A presumed benefit of automated systems is the reduction in the information-processing load placed upon operators. Such a presumption is not always tenable, however, especially where vigilance is concerned (Warm & Dember, 1998; Woods, 1996). Initially, it was believed that vigilance tasks were tedious but benign assignments which placed little demand upon operators (Frankmann & Adams, 1963;Welford, 1968), a view that might be easily inferred from the description of conditions in the typical vigilance experiment outlined above. However, evidence is emerging to indicate that while tedious, vigilance tasks are not benign. Instead, they impose high levels of mental workload on monitors, and operators find such tasks to be stressful (Grier, Szalma, Warm, Dember, Galinsky, & Parasuraman, 1999; Temple, Warm, Dember, Jones, LaGrange, & Matthews, in press; Warm, 1993; Warm, Dember, & Hancock, 1996). As Nickerson (1992) has emphasized, the workload and stress of monitoring tasks is an issue for concern given the potentially negative impact of such effects on worker health/productivity, a concern consistent with the broad problem of job-related stress that is receiving considerable interest in the human factors community (Sauter, Murphy, & Hurrell, 1990). Moreover, the problem of vigilance is difficult to avoid, since the human monitor will likely be needed to serve in a fail-safe capacity even in fully automated systems (Parasuraman, 1986). In view of the pervasiveness of vigilance in automated systems and of the effects of time on the quality of sustained attention, it is important to understand the characteristics of vigilance tasks which induce high levels of workload and stress and of the effects of *time itself* on these concomitants of sustained attention.

The Workload of Sustained Attention

Workload Measurement. Perceived mental workload refers to the information processing load or resource demands imposed by a task (Eggemeier, 1988; O'Donnell & Eggemeier, 1986). One of the most effective measures of perceived workload currently available is the NASA-Task-Load-Index (NASA-TLX; Hart & Staveland, 1988; Hill, Iavecchia, Byers, Zaklad, & Christ, 1992; Lysaght, et al. 1989; Nygren, 1991; Procter & Van Zandt, 1994), a multidimensional instrument that provides a reliable index of overall workload (test-retest correlation = .83) and also identifies the relative contributions of six sources of workload. Three of those sources reflect the demands that tasks place upon operators (Mental, Physical, and Temporal Demand), whereas the remainder characterize the interaction between the operator and the task (Performance, Effort, and Frustration). Using this scale, Warm, Dember, and Hancock and their associates conducted an extensive series of experiments which provided the initial assessment of the workload of sustained attention (summarized in Warm, Dember, & Hancock, 1996). They reported the cost of mental operations in vigilance to be substantial, with scores on the NASA-TLX falling at the mid-to-upper levels of the scale. The values obtained exceeded those typically observed with other types of tasks, including memory search, mental arithmetic, grammatical reasoning, simple tracking, and time estimation, and were similar to those obtained with the operation of a motion-based flight simulator (Hancock, 1988; Hart & Staveland, 1988; Liu & Wickens, 1987; Sanderson & Woods, 1987). In addition, Warm, Dember, and Hancock (1996) also reported that Mental Demand and Frustration were the principal components of workload. These results have also been described in several other experiments using the NASA-TLX (Becker, Warm, Dember, & Hancock, 1991; Deaton, & Parasuraman, 1993; Dittmar, Warm, Dember, & Ricks, 1993; Matthews, 1996; Scerbo, Greenwald, & Sawin, 1993; Temple, et al., in press; Warm, Dember, & Parasuraman, 1991).

Determinants of Workload. Warm, Dember, and Hancock (1996) have noted that while the NASA-TLX is a convenient and reliable instrument for measuring mental workload, it is essentially a subjective scale, and as Natsoulas (1967) has indicated, there is always some question as to whether any form of self-report accurately reflects respondents' "true" perceptual experiences. In order to establish the validity of ratings of perceived workload in vigilance experiments, Warm, Dember, and Hancock and their associates sought to bring such workload ratings under experimental control by demonstrating that factors which degrade vigilance performance increase workload ratings, while factors that enhance performance diminish perceived workload. This research strategy has been quite successful in uncovering several factors which affect the workload of sustained attention.

One of the first issues to be addressed in this way was the role of time on task. Dember, Warm, Nelson, Simons, Hancock, and Gluckman (1993) demonstrated that the vigilance performance decrement is accompanied by a systematic rise in global workload over time. In their study, the workload of observers was assessed after one, two, three, four, or five 10-min periods of watch on a task requiring visual spatial discriminations. Overall workload ratings increased linearly with time on task at the rate of 3.2 units of workload/10 min period of watch.

In addition to time on task, several stimulus factors which serve to degrade vigilance performance have also been found to elevate the workload of vigilance tasks. These include signal salience, event rate, spatial uncertainty, and display complexity. As in many perceptual tasks, the speed and accuracy of signal detections in vigilance vary directly with the salience or discriminability of the signals presented to the observers (Adams, 1956; Guralnick, 1972; Hawkes & Loeb, 1962; Loeb & Schmidt, 1963; Parasuraman & Mouloua, 1987; Metzger, Warm, & Senter, 1974; Thurmond, Binford, & Loeb, 1970; Tickner, Poulton, Copeman, & Simmonds, 1972). Gluckman, Warm, Dember, Thiemann, and Hancock (1988) explored the effects of signal salience on perceived workload using signals that were either highly salient or difficult to detect. As might be anticipated, signal detection was greater in the high- than in the low-salience condition. This effect was accompanied by a greater level of reported workload in the low-as compared to the high-salience condition.

Vigilance tasks typically make use of dynamic displays in which critical signals for detection appear within an ensemble of recurrent non-signal events. For example, in Mackworth's Clock Test described earlier, the small 0.3 in movements of the pointer constituted a background of neutral events in which critical signals for detection, the larger 0.6 in movements, were embedded. Although the background events may be neutral in that they usually require no response from observers, they are far from neutral in their effects on performance efficiency. Many investigations have demonstrated that detection efficiency varies inversely with the rate of repetition of neutral background events, or the *background event rate* (cf. Jerison & Pickett, 1964; Lanzetta, Dember, Warm, & Berch, 1987; Loeb & Binford, 1968; Parasuraman, 1979). The consistency of this outcome has led to the nomination of event rate as the prepotent psychophysical determinant in the maintenance of sustained attention (Davies & Parasuraman, 1982; Mackworth, 1968, 1969; Warm & Jerison, 1984). Using a dual-task procedure in which observers were instructed that a vigilance task was their prime responsibility and a probe detection task secondary -- a standard procedure for assessing the resource demand of a primary task (Wickens, 1984) -- Bowers (1983) and Parasuraman (1985) found that the response times to the secondary probes were greatly elevated when they occurred in the presence of a fast as compared to a slow primary task event rate. Thus, these studies demonstrated that event rate has a considerable impact on the resource demands of a vigilance task. This result is complemented by the findings of Galinsky, Dember, and Warm (1989) that event rate schedules of 5 and 40 events/min are accompanied by an increase in workload on the NASA-TLX from a score of 45 at the slow event rate to 62 at the fast event rate.

Alluisi (1966) has likened observers in vigilance experiments to lookouts in the "crow's nest" of old time sailing vessels who stood watch for potential targets with no knowledge about where in their field of view targets would appear. In vigilance experiments such spatial uncertainty can be manipulated experimentally by presenting the stimulus to be detected in different display loci at random. Jonides (1981) and Liu and Wickens (1992) have noted that attending to visual space involves an automatic orienting component and an effortful, resource-draining search and scanning component. Thus, increasing spatial uncertainty increases the amount of scanning required to monitor the vigilance display and hence, the amount of effortful attention. Consistent with this idea, increasing spatial uncertainty reduces the speed and accuracy of signal detection in vigilance (Adams & Boulter, 1964; Lisper, & Tornros, 1974; Milosevic, 1974; Warm, Dember, Murphy, & Dittmar, 1992) and elevates the workload of sustained attention (Sullivan, 1991).

The scanning imperative inherent in experiments manipulating the spatial uncertainty of a single stimulus element in a unitary display is also present when critical signals are defined as a unique conjunction of several different stimulus elements appearing simultaneously at separate locations on a given display, or when observers must simultaneously monitor multiple displays. Both of these conditions have been found to have harmful effects upon the probability of signal detections and to elevate the perceived mental workload of the vigilance task (Grubb, Warm, Dember, & Berch, 1995; Miller, Warm, Dember, & Schumsky, 1998).

In addition to the factors just described which serve to degrade vigilance performance, the quality of sustained attention can be enhanced by providing observers with knowledge of results as to the speed and accuracy of their responses (Becker, Warm, Dember, & Hancock, 1995; Chinn & Alluisi, 1964; Dittmar, Warm, & Dember, 1985; Hardesty, Trumbo, & Bevan, 1963; McCormack, 1959; Szalma, Miller, Hitchcock, Warm, & Dember, 1998; Warm, Epps, & Ferguson, 1974) and by cueing observers about the impending arrival of critical signals to be detected (Aiken & Lau, 1967; Annett, 1966; Annett & Patterson, 1967; Hitchcock, Warm, Dember, Moroney, & See, in press; Wiener & Attwood, 1968). Knowledge of results is considered to affect performance through enhanced motivation and by fostering observers' awareness of important task relevant characteristics (Szalma, Miller, Hitchcock, Warm, & Dember, 1998; Szalma, Parsons, Warm, & Dember, 1999; Warm, & Jerison, 1984; Wiener, 1963), while the beneficial effects of cueing are held to result from reductions in the observing and decision making demands on monitors (Hitchcock, et al. in press). Both of these factors not only enhance vigilance performance, they also lower the workload associated with the vigilance task (Becker, et al. 1995; Hitchcock, et al. in press).

The Role of Sensory Modality. It is evident that a number of factors have been identified which can be linked to the information-processing demands of vigilance tasks and which affect the perceived mental workload of these tasks. It is noteworthy, that to date, experiments on the workload of sustained attention have utilized only visual displays. However, modern automated systems are focusing increasingly upon auditory display technology (Moroney, 1999) and the sensory modality of signals makes a difference in the efficiency with which operators can perform vigilance tasks (Warm &

Jerison, 1984). Several studies have demonstrated that the speed and accuracy of signal detections tend to be greater for auditory than for visual signals (Baker, Ware, & Sipowicz, 1962; Buckner & McGrath, 1963; Colquhoun, 1975; Craig, Colquhoun, & Corcoran, 1976; Jones & Kirk, 1970; Warm & Alluisi, 1971) and that the vigilance decrement is less steep for acoustic vigilance tasks than for their visual analogs (Sipowicz & Baker, 1961; Ware, 1961).

Hatfield and Loeb (1968) have shown that these sensory effects arise from differential "coupling" inherent in the auditory and visual modalities. Auditory tasks are "closely coupled" because monitors in those tasks are usually linked to a source of stimulation either through headphones or through an enveloping sound field. Hence, their physical orientation does not determine their receptiveness to stimuli. In contrast, monitors in visual tasks are "loosely coupled" since they are typically free to make head and eye movements which can be incompatible with observing the display, and their physical orientation is crucial in determining their receptiveness to the stimuli to be monitored. To overcome the coupling disparity, observers in visual tasks must maintain a relatively fixed posture which can lead to discomfort and restlessness (Galinsky, Rosa, Dember, & Warm, 1993; Hunting, Laubli, & Grandjean, 1981). In addition, observers in visual tasks are also susceptible to asthenopia (visual fatigue) and tension, which are often encountered in tasks involving the use of video display terminals (Dainoff, Happ, & Crane, 1981; Galinsky, et al., 1993; Jaschinski-Kruza, 1991; Rey & Meyer, 1980). Thus, efforts to work through the negative effects of such consequences when faced with the need to continuously observe displays for critical signals may result in an elevated level of workload for visual as compared to auditory monitoring. Accordingly, the sensory modality of signals could be an additional component to the compendium of factors responsible for the workload of sustained attention. One goal for the present study was to explore this possibility.

The Stress of Sustained Attention

Stress Defined. From a human factors perspective, stress has conventionally been viewed as arising from the operator's physical and social environment (Hockey, 1984, 1986; Proctor & Van Zandt, 1994; Wickens, 1992; Wickens, Gordon, & Liu, 1998). However, individuals may also be stressed by the tasks they need to perform. This has led Hancock and Warm (1989) to suggest that in order to understand the role of stress in human performance, it is necessary to revise traditional views of stress as an independent environmentally and/or socially determined agent that acts on performance and recognize that *tasks themselves* can be a significant source of stress. As they indicate, vigilance is a case-in-point.

Prior to examining the stress of sustained attention, however, it is first necessary to specify the meaning of the term "stress." That task is more difficult than it would intuitively appear (Alluisi, 1982; Asterita, 1985) because there are several ways in which stress may be conceptualized. Traditional models defined stress solely in terms of the stimuli involved, for example, noise, temperature or vibration (Cox, 1978; Elliott & Eisdorfer 1982). Stimulus based views have been found wanting, however. A theory that defines stress only in terms of the nature of the stimulus cannot account for why the same stimulus can induce different stress responses across individuals, or within the same individual on different occasions (Hockey, 1986; Hockey & Hamilton, 1983; Matthews, in press).

More biologically based approaches defined stress in terms of the physiological response patterns to a stimulus (Asterita, 1985; McGrath, 1970; Selye, 1976). An early example of such an approach was that of Cannon (1932) who conceptualized negative emotion in terms of autonomic nervous system activation triggered by a homeostatic challenge. According to Cannon, deviations from homeostatic equilibrium can be fostered by external conditions (e.g. cold, heat) or internal deficiencies (e.g. low blood sugar), and any threat to equilibrium results in physiological responses aimed at countering that threat. These responses involve sympathetic activation of the adrenal medulla and the release of several hormones (see Asterita, 1985 and Dunbar, 1954 for reviews).

The response-based approach of Cannon was continued by Selye (1976), who defined stress in terms of an orchestrated set of bodily defenses against any form of noxious stimulation, a set of physiological reactions and processes referred to as the *general adaptation syndrome* (Asterita, 1985; Lazarus & Folkman; 1984; McGrath, 1970). Environmental objects or events that give rise to such responses were referred to as "stressors." Within Selye's theory, physiological responses to stressors are general in character, since the set of responses is similar across different stressors and contexts.

One of the most widely applied physiological response-based theories of stress and performance has been arousal theory. *Arousal level* is a hypothetical construct representing a nonspecific (general) indicator of the level of stimulation of the organism as a whole (Hockey, 1984). Arousal may be assessed using techniques such as electroencephalography (EEG) or indicators of autonomic nervous system activity such as the galvanic skin response (GSR). As a person becomes more aroused, the waveforms of the EEG increase in frequency and decrease in amplitude, and skin conductance increases.

Within this framework, stress effects are observed under conditions of either overarousal (e.g. noise) or underarousal (e.g. sleep deprivation; Hockey, 1984; McGrath, 1970). This approach assumes an inverted U-relation between arousal and performance, such that the optimal level of performance is observed for mid-range levels of arousal (the Yerkes-Dodson Law). Stressors, such as noise or sleep loss, exert their influence by either increasing or decreasing the arousal level of the individual relative to the optimum level for a given task (Hockey & Hamilton, 1983). That level is inversely related to the difficulty of the task (Hockey, 1984, 1986).

There are several problems with the arousal theory of stress and performance. First, the different physiological indices of arousal do not tend to correlate well. For example, during a vigil muscle tension, as measured by EMG, or catecholamine levels might indicate an aroused state, but skin conductance might indicate that the observer is de-aroused (Hovanitz, Chin, & Warm, 1989; Parasuraman, 1984). Second, it has proven difficult to define the effects of stressors on arousal independent of effects on performance (Hockey, 1986). Third, the theory can accommodate almost any results, making it a post-hoc position which is difficult to falsify (i.e. test empirically; Hockey, 1984). Finally, arousal theory assumes that a stressor (or set of stressors) affects overall processing efficiency and that differences in task demands (i.e. difficulty) are reflected only in the position of the optimal level of performance. Hockey and Hamilton (1983) have noted, however, that environmental stressors can have differential effects on the *pattern* of cognitive activity, and a single dimension, as posited by arousal theory, cannot easily account for such differences among stressors. Hence, a multi-dimensional approach is necessary in order to understand stress.

An effort to circumvent the difficulties that accompany the stimulus-based and physiologically-based models of stress is a cognitive approach wherein stress is described in terms of person-environment interactions. Within the framework of a transactional model, stress states may be viewed as abstracted representations of the relation between individuals and the external demands placed upon them (Matthews, Joyner, Gilliland, Campbell, Falconer, and Huggins, 1999). Lazarus and Folkman (1984) defined psychological stress as a case in which individuals appraise their environment as taxing or exceeding their resources and/or endangering their well being. The negative effects of stress are most likely to occur when individuals view an event as a threat, and when they assess their coping skills as inadequate for handling the stressor. The transactional model is vague, however, in regard to the specific circumstances under which certain stress outcomes occur (e.g. health problems, mood shifts), and in making predictions regarding whether a particular person-environment transaction will impair performance (Matthews, in press).

The cognitive state model formulated by Hockey (1984; 1986) relates particular sources of stress in the environment to specific *patterns* of cognitive activity and performance change. Thus, different environmental stressors are associated with different patterns of change in information processing. Moreover, such changes can be associated with either the structure of these processes (e.g. working memory demands; rate of information transmission) or the strategies individuals employ in response to stress (e.g. allocation of resources; decision criteria; Hockey & Hamilton, 1983). Strategy and structure effects seem to reflect different aspects of cognitive function, and as such, should show different performance outcomes in the presence of particular stressors.

Lazarus and Folkman's (1984) transactional model and Hockey's (1984; 1986) cognitive state model are not incompatible, but may in fact be complementary. The transactional model emphasizes the importance of cognitive appraisals of stressful events, and the individual's subjective responses to stressful stimuli, but it does not address the human factors problem of how task parameters influence appraisals, information processing, and subjective and behavioral stress responses. On the other hand, the cognitive state model addresses the relation between specific stressors and changes in patterns of cognitive activity, but it neglects the appraisals individuals make regarding stressful events, which may mediate stressor effects.

For the purposes of the present investigation, the complementary multi-dimensional characterizations of stress offered by the transactional and cognitive state models will be adopted. That is, psychological stress will be broadly viewed as a case in which individuals appraise their environment as taxing or exceeding their resources and/or endangering their physical or psychological well being. Such appraisals, however, will be assumed to be affected by the characteristics of the stressor (in this case task demands). Further, the way in which individuals view their ability to cope with task demands may influence multiple dimensions of task-related processing and subjective response.

Physiological Indicants of Stress in Vigilance. The stress of sustained attention has been assessed both physiologically and in terms of self-reports of mood and fatigue. On the physiological level, elevated amounts of circulating catecholamines (epinephrine and norepinephrine) and corticosteriods released into the bloodstream are generally considered to be indicants of stress (Asterita, 1985; Dunbar, 1954; Parasuraman, 1984; Wesnes & Warburton, 1983), and several studies have employed these measures to explore the physiological stress response associated with vigilance. In an early study, Frankenhaeuser, Nordheden, Myrsten, and Post (1971) measured the catecholamine levels of observers who experienced either a sustained attention task or a complex sensorimotor task requiring button pressing, pedal pushing, and lever pulling responses. Observers in a control group read magazines. Frankenhaeuser and her associates observed that catecholamine levels increased over time for the sensorimotor and sustained attention tasks and decreased for the control condition, a result which was replicated in an additional study by Lundberg and Frankenhaeuser (1979). The Frankenhaeuser, et al. (1971) study also revealed a positive correlation between adrenaline secretion and performance on the vigilance task, indicating that observers whose adrenaline levels increased over the course of a vigil detected more signals than those whose levels were relatively low. These results led the authors to suggest that there is a physiological cost, in terms of stress, to enhanced performance and that the elevated catecholamine levels may represent an attempt by observers to compensate for the underarousal, as reflected in autonomic measures such as heart rate and GSR, which is often induced by vigilance tasks (see Davies and Parasuraman 1982 for a review of measures of arousal in vigilance). Positive correlations between adrenaline concentration and vigilance performance have been reported in several other studies (Johansson, 1970; O'Hanlon, 1965; O'Hanlon & Beatty, 1976), and observers who have had prior experience with a vigilance task have been found to exhibit higher adrenaline levels while waiting to engage that task again than controls who simply waited to view movies (O' Hanlon, 1965). As Galinsky (1991) has noted, it would seem that merely anticipating a vigilance task is sufficient to induce a physiological stress response.

Other physiological measures of vigilance-induced stress have included indices of muscle tension, body movement, and tremor. Thus, Hovanitz, Chin and Warm (1989) asked observers to monitor the apparent lateral movement of a horizontal bar for changes in distance. Electromyographic measures of activity in the frontalis muscles indicated an increase in muscle tension over the course of the vigil. In addition, the vigilance task produced tension headaches in sensitive observers. Carriero (1977) has also reported increments in muscle tension during a vigil, and Temple and his associates (1997) have confirmed that vigilance tasks can be responsible for the development of tension headaches (Temple, Dember, Warm, Hovanitz, McNutt, & Bierer, 1997). Restlessness was examined in a study by Thackray et al (1977), in which body movements, recorded by means of a pulse transducer located under the observer's seat cushion, increased with time on a simulated air-traffic control task. Similarly, Galinsky, Rosa, Warm, and Dember (1993) used an activity monitoring system affixed to the observer's dominant wrist to measure physiological tremor while observers monitored a visual or auditory display for changes in signal duration. They found that tremor increased over the course of the vigil. Of particular pertinence for the present investigation, Galinsky and her associates found that the temporally-based increment in tremor was greater for the visual than for the auditory task.

In sum, the studies described above converge on the finding that vigilance performance is associated with physiological stress but that these effects are multidimensional in character. For example, GSR and heart rate data suggest that the stress of sustained attention is linked to underarousal while data regarding EMG activity and tremor responses suggest that the stress of vigilance is tied to overactivity in physiological systems.

Self-Report Indicants of Stress in Vigilance. In addition to physiological indicants, self-report measures of mood and fatigue can also provide a window into the nature of vigilance-induced stress, a window which offers a somewhat different vista than physiology. For example, self-report measures of stress are correlated with physiological measures, but the correlations are not as strong as one might expect if the various measures tap the same phenomenon (Matthews, in press). In addition, self-report measures of stress are more closely coupled with cognitive states than physiological measures and therefore may provide a clearer picture of the *psychological* processes underlying stress (Thayer, 1989). Thus, self-report measures of the stress of vigilance were of primary concern in this study.

An early attempt to assess the subjective state associated with a vigilance task was that of Thackray, Bailey, and Touchstone (1977) described above in regard to body movement. Prior to the vigil and following its completion, observers were administered an instrument which assessed their present feelings, attitudes, and emotions. The observers ware asked to rate, on a 9-point scale, their levels of attentiveness, strain, boredom, irritation, and fatigue. They indicated that they felt less attentive and more strained, bored, irritated, and fatigued after the vigil than prior to its start.

Other vigilance studies using the Thackray scales have replicated these findings (Hovanitz, et al, 1989; Lundberg, Warm, Seeman, & Porter, 1980; Thiemann, Warm, Dember, & Smith, 1989; Warm, Rosa, & Colligan, 1989). In addition, Warm and his colleagues (Galinsky, Rosa, Warm, & Dember, 1993; Thiemann, et al., 1989; Warm, Dember, & Parasuraman, 1991) have shown increases in sleepiness and fatigue following a vigil, as measured by the Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), and a scale of symptoms of fatigue developed by Yoshitake (1978), and several experiments have demonstrated high level of boredom in vigilance tasks (Hitchcock, et al., in press; O'Hanlon, 1981; Scerbo, 1998).

The Dundee Stress State Questionnaire. Although they have been successful in revealing the stress of vigilance, the instruments discussed above may not provide the most sophisticated approach for that purpose. For example, the Thackray scale is based on single rating scales, each of which supposedly represent a dimension of stress. However, the distinctions between the various dimensions of the Thackray scale have not been empirically validated. The Yoshitake and boredom scales that have been used are also of limited value, since they tap only unidimensional aspects of stress states, and thus do not capture the multidimensional nature of the construct.

Recently, Matthews, Joyner, Gilliland, Campbell, Falconer, and Huggins, (1999) developed the Dundee Stress State Questionnaire (DSSQ) for assessing transient states associated with mood, arousal, and fatigue. It is designed to reflect the multidimensional nature of stress. This instrument consists of 77 items that yield ten factor-analytically determined scales, measuring 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 were subjected to another, second order factor analysis, yielding three secondary factors: Task Engagement, Distress, and Worry (Matthews, et al, in press). *Task Engagement*, defined primarily by the Energy, Motivation, and Concentration scales, contrasts enthusiasm and interest with fatigue and apathy. Tense Arousal, Hedonic Tone, and Confidence and Control define the *Distress* factor while the *Worry* factor is defined by Self-Focused Attention, Self-Esteem, Concentration, and both kinds of Cognitive Interference.

Several studies have employed the DSSQ to assess the stress of sustained attention. In the initial investigation, Matthews, et al (1999) reported that participation in vigilance tasks led to *decreases* in Energetic Arousal, Concentration, and Motivation, indicating a loss of *Task Engagement* and an increased level of fatigue (Matthews & Desmond, 1998). Hedonic Tone and Confidence also decreased in the Matthews, et al. study, indicating a greater degree of *Distress.* These findings have been replicated by Grier, Szalma, Warm, Dember, Galinsky, and Parasuraman (1999) and by Helton, Dember, Warm, and Matthews (in press). Other demanding tasks elicit qualitatively different patterns of response: for example, working memory tasks elicit increased distress along with increased task engagement (Matthews, et al., 1999).

Task Determinants of Self-Reported Stress. Given its success in revealing the multidimensional nature of subjective stress in vigilance, the DSSQ was the instrument of choice in the present effort to go beyond the mere identification of such stress and to explore the factors which induce it. It is likely that the stress of sustained attention arises, in part, from the need to make continuous signal/nonsignal decisions under conditions of great uncertainty with little opportunity for situational control. Such a view is consistent with Warm, Dember, and Hancock's (1996) account of the origins of the workload of sustained attention and with findings that the stressfulness of many situations stems from the individual's lack of control over them (Averill, 1973; Nickerson, 1992). In addition, Hancock (1998) and Scerbo (1998) have suggested that the imposition of vigilance tasks upon monitors by an external authoritative agency (the experimenter in laboratory studies; management in operational settings) under conditions in which monitors cannot easily quit adds to the aversiveness of the task.

An account of the genesis of stress in sustained attention along these lines is global in character, however, and does little to pinpoint the specific elements of the vigilance task itself which may affect monitors' stress reactions. Indeed, evidence is available to indicate that such determinants may play a key role in the manner in which task imposition, and the need to make continuous signal/nonsignal decisions, impact subjective stress reactions. Using the DSSQ, Temple, Warm, Dember, Jones, LaGrange, and Matthews (in press) found evidence of subjective stress in an abbreviated vigil lasting only 12 min. Their observers reported post-vigil increases in Tense Arousal and declines in Hedonic Tone, Confidence, and Intrinsic Task Motivation. These effects were noted, however, only among observers who detected low salience (hard) signals. Observers in a high signal salience (easy) condition did not report the task to be stressful. Thus, like workload, signal salience also appears to influence the stress of sustained attention. This influence is revealed along a broad array of subjective stress dimensions, but merely requiring observers to make repetitive signal/noise decisions in a vigilance task imposed upon them in a laboratory setting is not sufficient to elicit stress reactions. For that to happen, difficult discriminations are required.

Still another task dimension which has been found to influence the subjective stress of vigilance is the sensory modality of signals. In addition to elevated level of restlessness, Galinsky and her associates (1993) found that observers engaged in a visual sustained attention task reported a greater level of stress than those monitoring an auditory display. They suggested that the modality difference might arise because, in comparison to observers in the visual task, those in the auditory task were free from the negative effects of postural constraint, tension, and asthenopia, factors which were described earlier in connection with the potential for modality differences in perceived workload.

It is worth noting, however, that the subjective stress effects described in the Galinsky, et al. study were limited to self reports of *fatigue* on the Yoshitake Symptoms Fatigue Scale (Yoshitake, 1978), and no effort was made to determine if modality-based effects extend to *other dimensions* of subjective stress. Accordingly, together with assessing the effects of the sensory modality of signals on perceived mental workload, the present study also sought to determine the multidimensionality of sensory-determined stress in sustained attention by means of the DSSQ. In addition, the present study was designed to determine the manner in which self-reports of stress change over time. To date, temporal changes in self-reports of the stress of vigilance have been entirely *neglected*. Given that time is a key element in vigilance performance and that physiological stress grows with time, a complete understanding of the nature of self-reports of stress requires information on their temporal rate of gain. In view of past findings, it is anticipated that (1) those DSSQ dimensions which reveal task-induced stress will show greater levels of stress for a visual as compared to an auditory vigilance task and (2) those DSSQ dimensions which reveal task-induced stress will show that the negative effects of participating in the vigil will increase with time on watch.

CHAPTER II

Method

Participants. Two-hundred and fifty-six undergraduates at the University of Cincinnati (128 men and 128 women) served as participants in order to fulfill a course requirement. They ranged in age from 18 to 39 years, with a mean of 20.3 years. All observers had normal or corrected to normal vision and were free of known hearing impairments.

Experimental Design. Two sensory modalities (auditory and visual) were combined factorially with four vigil durations (10, 20, 30, or 40 min). Thirty-two observers were assigned at random to each of eight *independent* groups resulting from the combinations of sensory modality and vigil duration, with the restriction that the experimental conditions were equated for sex.

Apparatus and Measurement: Performance. In order to assess the effects of audio-visual channels per se on vigilance performance, workload, and stress, it was necessary to utilize a dimension for discrimination that is common to the two modalities. Temporal discrimination was chosen for that purpose since audio-visual correlations in the discrimination of temporal intervals are substantial ($r = 0.90$; Loeb, Behar, & Warm, 1966) and skill in making precise temporal judgments acquired through training in one modality readily transfers to the other (Warm, Stutz, & Vassolo, 1975).

Observers monitoring the visual display viewed the repetitive presentation of a horizontally oriented 2 mm x 9 mm white bar which appeared against a gray background on a video display terminal (VDT). The luminance of the bar was 37.8 cd/m^2(as measured by a Spectra-Model UBD 1° Spot Meter), while that of the gray background was 3.49 cd/m^2. Neutral events, those requiring no overt response from the observer, were flashes lasting 247.5 ms. Observers monitoring the auditory display listened to 247.5 ms bursts of white noise presented binaurally via Grayson-Stadtler TDH-39 headphones. In order to control for the effects of wearing headphones, observers in the visual conditions were also required to wear them for the duration of the vigilance session. For each participant, the apparent loudness of the noise was matched to the apparent brightness of the visual stimulus by means of a cross-modality matching procedure (Stevens, 1959). In the visual case, critical signals for detection were brief 125 ms flashes of the light bar. In the auditory case, critical signals were brief 200 ms noise bursts. The disparity in the duration changes used to specify auditory and visual critical signals was necessary to compensate for the fact that temporal discrimination is more acute in the auditory mode (Dember & Warm, 1979). The values used for neutral events and critical signals in this study are identical to those used by Galinsky, et. al (1993), and verified as to their equal discriminability under alerted conditions by pilot work preceding this study. In the pilot work, a sample of 20 observers discriminated critical from neutral events over 20 trials using a two-alternative temporal forced-choice procedure.

In both modalities, stimuli were presented at a rate of 40/min by setting stimulus onset asynchrony (SOA) at 1.5 sec. Ten critical signals occurred within each 10-min period of watch (signal probability = 0.025). Observers responded to critical signals by pressing a signal key on a response pad attached to an Apple Power Mac computer keyboard. The computer orchestrated stimulus presentations and recorded observers' responses. Responses occurring within 1.5 sec. after the onset of a critical signal were recorded automatically as correct detections. All other responses were recorded as errors of commission or false alarms. Participants were tested individually in a 2.0 x 1.9 x 1.9 m Industrial Acoustics Sound Chamber. They were seated in front of the VDT, which was positioned at eye level approximately 35 cm from the observer. Ambient illumination in the chamber was 0.26 cd/m^2, and was provided by a 25-W bulb housed in a parabolic reflector behind and to the right of the observer. The bulb served to diffuse the light evenly, minimizing the glare on the VDT. Fresh air was supplied by a fan mounted in the chamber wall above and behind the observer.

Apparatus and Measurement: Perceived Workload and Stress. Perceived mental workload was measured by a computerized version of the NASA Task Load Index (NASA-TLX), which was administered immediately after the vigilance session. Perceived stress was measured using the Dundee Stress State Questionnaire (DSSQ). The DSSQ was administered in two parts: a pre-vigil questionnaire completed prior to the initiation of the vigil, and a post-vigil questionnaire completed after the vigil. To avoid possible testing bias, half the observers (equated for sex) in each sensory modality-vigil duration group were administered the TLX, while the remaining half completed the DSSQ. Copies of the pre- and post-versions of the DSSQ, and the instructions for completion of the TLX, can be found in Appendix A.

Procedure. Upon entering the laboratory, participants surrendered their wristwatches and/or pagers, read a brief description of the experiment, and signed a consent form. Each participant was then seated in the testing chamber and the cross-modality matching procedure was administered. The experimenter then read the instructions for the sustained attention task which were simultaneously presented on the VDT. These instructions, as well as those for the cross-modality matching procedure, are provided in Appendix B. Following the instructions, half the participants completed the pre-version of the DSSQ, and then engaged in a 5-min practice session with the sensory modality they would later encounter in the main portion of the session. The remaining participants proceeded directly to the practice session after reading the instructions. All participants were required to detect a minimum of 80% of the critical signals and commit no more than 10% false alarms during practice. Observers failing to pass this criterion were provided a second 5-min practice session. Only the data of those participants who passed criterion on either the first or second practice session were included in the study (13 participants -- 5% of the total sample -- could not meet the performance criteria and needed to be replaced). The mean percentage of correct detections at the end of practice was 95% for observers in each sensory modality. The main vigil commenced immediately after participants completed the qualifying practice period. Observers had no prior knowledge of the length of the vigil, other than that it would not exceed 75 min.

CHAPTER III

Results

Performance

Signal Detections. Mean percentages of correct detections in the auditory and visual tasks are plotted as a function of periods of watch in Figure 1. In this, and all subsequent analyses, the data for the 20-min, 30-min, and 40-min groups are based only upon the final 10 min of the vigil and upon *independent* groups of participants.

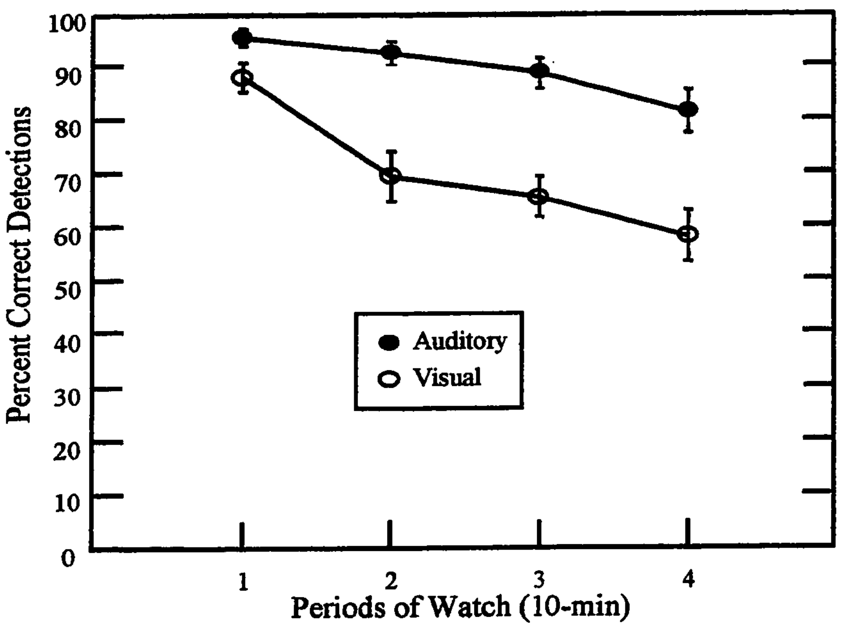

Figure 1. Percent correct detections as a function of periods of watch (10-min). Error bars are standard errors.

It can be seen in Figure 1 that overall detection probability was greater in the auditory (M=89.9%) than in the visual condition (M= 70.6%), that detection probability generally declined over time, and that the vigilance decrement tended to be greater for visual as compared to auditory signals. These impressions were mostly confirmed by a 2 (Modality) x 4 (Time) between-groups analysis of variance (ANOVA), based upon an arcsine transformation of the detection scores, which revealed significant main effects for modality, F (1, 248) = 60.24, $p < .001$ and time on watch, F (3, 248) = 14.94, $p < .001$. The interaction between these factors, however, was not significant ($p > .05$). [1]

False Alarms. Mean percentages of false alarms in the auditory and visual tasks are shown for each period of watch in Table 1. It is evident that false alarm rates in this study were low. The mean percentage of false alarms across all conditions was 1.1% with five of the eight conditions having a mean false alarm rate below 1%. A 2 (Modality) x 4 (Time) between-groups ANOVA, based upon an arcsine transformation of the false alarm scores, revealed no significant effects for Modality, Time, or their interaction ($p > .05$ in each case).

Table 1.
Mean percentages of false alarms in all experimental conditions. (Standard errors are in parentheses)

	Periods of Watch (10-min)				
Modality	10 min	20 min	30 min	40 min	Mean
Auditory	1.3 (0.5)	2.5 (1.2)	1.8 (1.3)	0.7 (0.3)	1.6
Visual	0.6 (0.2)	0.9 (0.5)	0.6 (0.3)	0.6 (0.2)	0.7
Mean	1.0	1.7	1.2	0.6	1.1

[1] Summary tables of all statistical analyses are presented in Appendix C.

Workload

Overall workload. Mean overall workload scores on the NASA-TLX for the auditory and visual tasks are plotted in Figure 2 as a function of periods of watch.

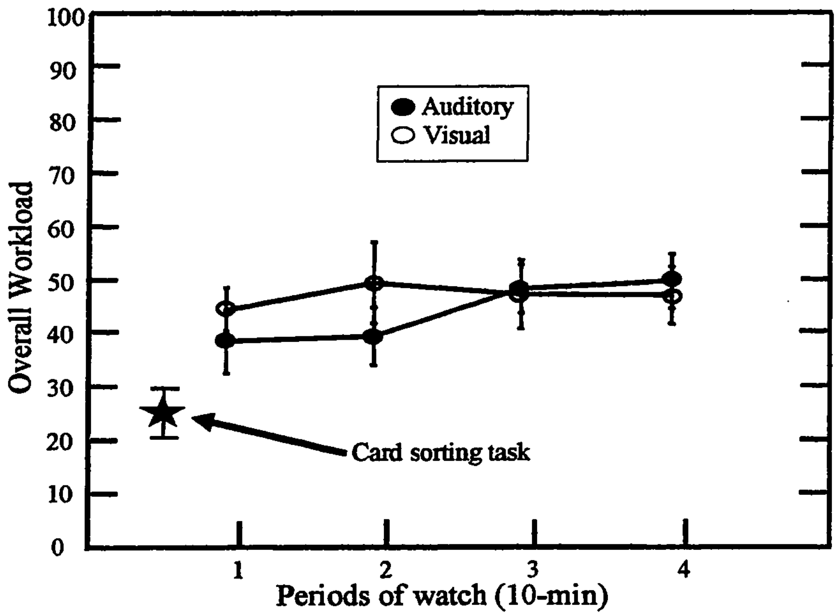

Figure 2. Overall workload scores as a function of periods of watch (10-min). Error bars are standard errors.

It can be seen in the figure that the overall workload scores for both the auditory and the visual tasks were similar and substantial; the scores for both tasks fell within the mid-range of the scale and were considerably higher than those for a 5-min card-sorting task based upon an additional 32 observers (16 male and 16 female undergraduates from the University of Cincinnati) which was carried out for comparison purposes. Observers sorted for suit at a rate of one card/sec while timed by a computerized metronome. A 2 (Modality) x 4 (time) between-groups ANOVA revealed no significant modality or time effects and no significant interaction between these factors in the overall workload scores of the two vigilance tasks ($p > .05$ in each case). The finding that the vigilance-based workload scores in this study exceeded those of the card-sort task indicates that the absence of modality and time effects in overall workload cannot be attributed to a lack of sensitivity in the TLX.

Weighted Workload Ratings. In addition to overall workload scores, mean weighted ratings on the subscales of the TLX were also determined in all experimental conditions. These values are presented in Table 2. It is evident in the table that Mental Demand (M= 165.4) and Frustration (M=177.7) contributed most to workload and that Physical Demand (M= 20.6) contributed least.

The data of Table 2 were subjected to a 4 (Periods) x 2 (Modality) x 5 (Subscales) mixed-ANOVA with repeated measures on the last factor. Due to the paired-comparison procedure used in determining the dimensional weightings, the Physical Demand subscale was dropped from the ANOVA in order to meet the independence assumption of the statistical procedure. In this analysis, and all other analyses in this study involving repeated measures, Box's epsilon was used in computing degrees of freedom to correct for violations of the sphericity assumption (Maxwell & Delaney, 1990). The overall difference among the subscales was statistically significant, $F\ (3, 417) = 14.75$, $p < .001$, and there was a significant Subscale x Time interaction, $F\ (10, 417) = 2.02$, $p < .05$. None of the remaining sources of variance in the analysis were statistically significant ($p > .05$).

Table 2.
Mean weighted ratings for the TLX subscales in each experimental condition. (Standard errors are in parentheses).

		Scale						
Period of watch	Modality	MD	PD	TD	P	E	F	Mean
1	Auditory	168.1 (33.1)	10.0 (5.6)	76.2 (16.7	119.4 (22.1)	105.6 (25.0)	111.6 (29.6)	98.5
	Visual	183.4 (30.7)	11.9 (6.8)	148.1 (35.2)	78.8 (16.4)	98.8 (16.1)	153.1 (32.2)	112.4
2	Auditory	138.4 (30.7)	16.6 (9.5)	114.7 (22.8)	101.2 (24.2)	99.7 (25.1)	132.8 (26.3)	100.6
	Visual	240.9 (36.1)	6.2 (3.9)	141.3 (29.0)	63.1 (17.7)	132.5 (26.8)	160.0 (33.8)	124.0
3	Auditory	130.0 (25.0)	17.2 (10.1)	125.0 (31.2)	105.0 (20.7)	140.6 (30.4)	210.9 (34.2)	121.4
	Visual	163.8 (33.0)	18.4 (7.7)	135.9 (35.0)	70.9 (20.7)	142.8 (34.5)	182.5 (39.4)	116.0
4	Auditory	180.9 (38.8)	54.1 (23.7)	100.0 (22.7)	65.3 (14.9)	120.0 (19.2)	230.9 (39.8)	125.2
	Visual	117.5 (28.0)	30.0 (13.7)	104.4 (21.7)	116.9 (23.6)	103.1 (29.2)	239.7 (35.9)	118.6
Mean		165.4	20.6	118.2	90.1	117.9	177.7	114.6

Note. MD= Mental Demand, PD= Physical Demand, TD= Temporal Demand, P= Performance, E= Effort, F= Frustration.

Following a procedure recommended by Keppel (1991), the subscale x time interaction was examined further by testing the effects of time separately within each subscale. Significant time effects were found only for the Frustration subscale, F (3, 124) = 3.92, $p<.05$. In this case, a trend analysis indicated that the weighted ratings increased linearly over time, F_{lin} (1, 124) = 11.42, $p<.01$, and that there were no significant deviations from linearity, $F_{non\text{-}lin}(2,124) < 1$, $p > .05$. The weighted ratings for the Frustration subscale are plotted as a function of periods of watch in Figure 3. A least-squares procedure was used to determine the line of best fit to the data. It can be seen in the figure that observers' weighted Frustration ratings (WFR) increased at the rate of 35.9 units per 10-min period of watch (PW).

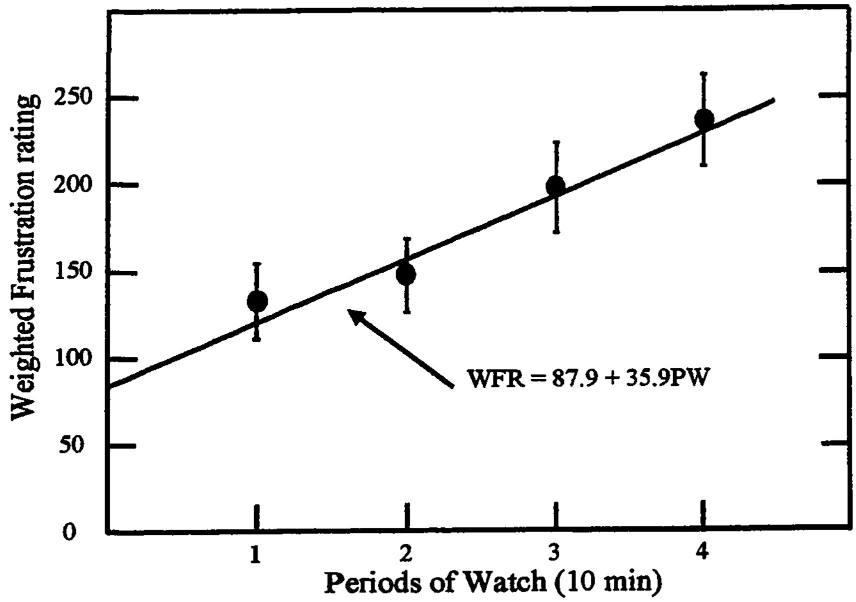

Figure 3. Weighted TLX Frustration rating as a function of periods of watch (10-min). Error bars are standard errors.

Stress

Standard Scores. All pre- and post-vigil comparisons on the DSSQ were made in terms of standard scores (z-scores) using equation 1:

$$z = \frac{\left(X_{phase} - \overline{X}_{normative}\right)}{S_{normative}} \quad [1]$$

Normative means and standard deviations based upon a British sample were obtained from Matthews, et al. (1999). This approach has the advantage of permitting a comparison of pre-vigil and post-vigil scores in the present study with the pre-performance values of a substantial normative group (N= 767).

Coarse-Grained Analysis. Stress data from the DSSQ were analyzed at two levels; a *coarse level* which determined if the outcome of the present study generally conformed to previous vigilance findings with the DSSQ by omitting the analysis of time and modality, and a *fine-grained level* which examined the multidimensional effects of the sensory modality of signals and periods of watch on the stress of sustained attention. The two-level approach was necessary because the fine-grained temporal analysis used in the present study could potentially mask earlier findings based upon a more gross analysis. Specifically, it is conceivable that a given DSSQ scale might show a change early in the vigil which then remained constant over the watch. Such a result would emerge as a null effect on the basis of a fine-grained temporal analysis, but as a meaningful effect if, as in prior studies, comparisons were made only on an overall pre-vigil/post-vigil basis. Modality was eliminated from the coarse analysis to avoid redundancy with the fine-grained examination of the data.

Mean pre-vigil (white rectangles) and post-vigil (shaded rectangles) standard scores collapsed across modalities and time periods are presented for the 10 scales of the DSSQ in Figure 4. It can be seen in the figure that pre-vigil scores hovered about zero for most of the scales, indicating that prior to serving in the vigil, the participants in this study were generally similar to those of the normative sample. The pre-vigil scores for each scale were tested against an hypothesis of no difference from the normative group (a standard score of zero) by means of t-tests using an alpha level of .05 and the Bonferroni correction. These tests revealed that prior to the vigil participants in this study had significantly more Confidence and Control and were significantly more Self-Focused than the normative group. Their scores on the other eight DSSQ scales did not differ significantly from the British norm group.

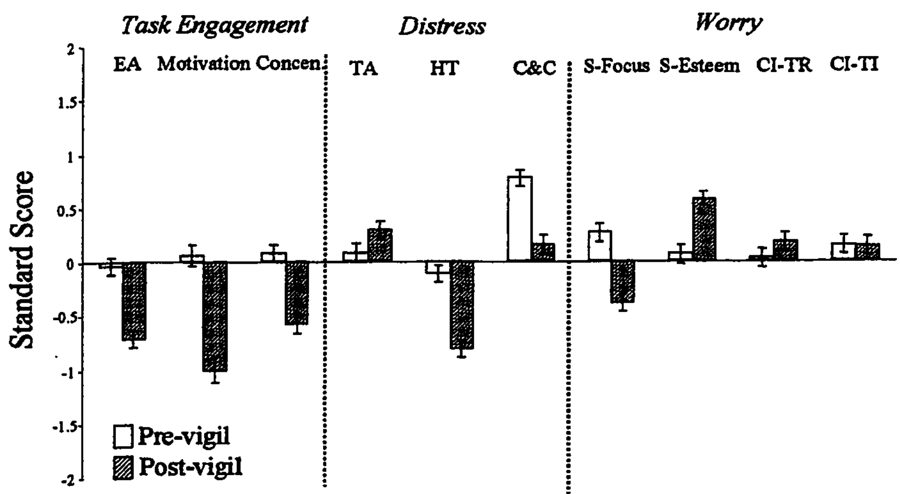

Figure 4. Pre- and Post-vigil standard scores for the scales of the DSSQ. Error bars are standard errors.
Note. EA= Energetic Arousal, Concen= Concentration, TA= Tense Arousal, HT= Hedonic Tone, C&C= Confidence and Control, S-Focus= Self-Focused Attention, S-Esteem= Self-Esteem, CI-TR= Task-Related Cognitive Interference, CI-TI= Task-Irrelevant Cognitive Interference.

Quite a different picture emerges when one examines the post-vigil DSSQ scores. It can be seen in Figure 4 that relative to their pre-vigil reports (white rectangles), observers' post-vigil scores (shaded rectangles) revealed that they felt less energized, motivated, less able to concentrate, and less happy, confident, and self-focused after the vigil than prior to its start. They also felt greater self-esteem post-vigil. Pre-post differences were tested for statistical significance by means of t-tests using an alpha level of .05 and the Bonferroni correction. All of the changes described above reached significance; changes on the remaining scales were not significant. In terms of the secondary factors of the DSSQ, participants tended to feel more *Distressed* (declines in Hedonic Tone and Control and Confidence) and less *Task Engaged* (declines in Energetic Arousal, Motivation, and Concentration) at the end of the vigil than before its start. For the most part, the coarse-grained examination of the DSSQ scores indicated that the vigilance task was stressful.

Fine-Grained Analysis. Prior to examining the effects of stimulus modality and time on task on the stress of sustained attention, it was necessary to demonstrate that observers in the modality and time conditions were similar to each other before the initiation of the vigil. Toward that end, mean pre-vigil standard scores for observers who would later experience one of the two sensory modalities at one of the four task durations are plotted separately for each of the 10 DSSQ scales in Figure 5. It can be seen in the figure that within each scale, the scores were similar for the two modality groups and for all of the task duration groups. A 2 (Modality to be Experienced) x 4 (Task Duration to be Experienced) x 10 (DSSQ Scales) mixed-ANOVA with repeated measures on the last factor indicated no significant main effects for modality or time, no significant two-way interaction between these factors, and no significant higher-order interactions between these factors and any of the DSSQ scales ($p > .05$). Clearly, the need for pre-vigil similarity in all combinations of sensory modality and task duration was met. While there were no significant effects involving the time or modality groups, there was a significant

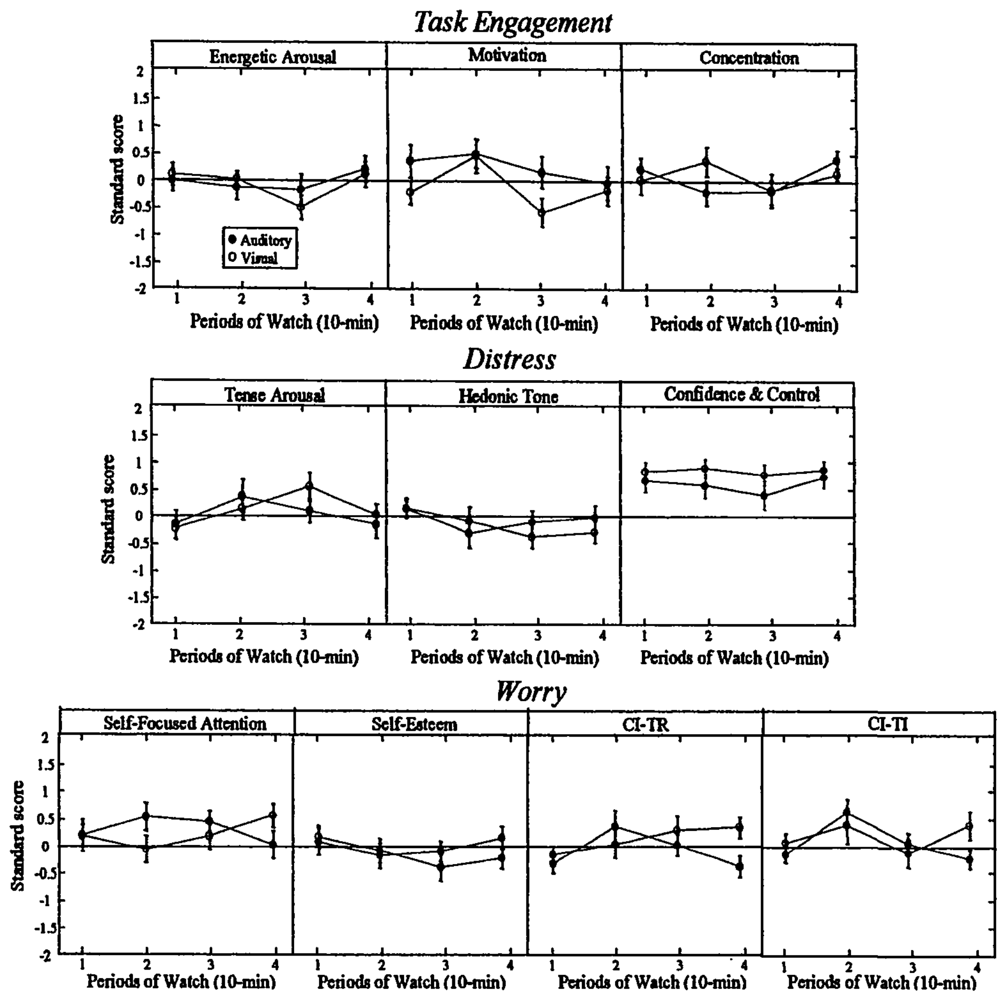

Figure 5. Pre-vigil DSSQ scores as a function of periods of watch for the auditory and visual tasks. Error bars are standard errors.

Note. CI-TR= Task-Related Cognitive Interference. CI-TI= Task-Irrelevant Cognitive Interference.

main effect for scales, F (5, 691) = 9.47, $p<.001$. Perusal of Figure 5 will reveal that as in the case of the coarse analysis, the Confidence and Control (M=0.78) and Self-Focused Attention (M=0.27) scales had the highest scores during the pre-vigil phase of the study.

Post-vigil standard scores are presented in Figure 6. For each DSSQ scale, the scores for the two sensory modalities are plotted as a function of time on task. Unlike the pre-vigil case, it is evident in Figure 6 that the post-vigil scores were not uniformly similar for these factors within each DSSQ scale. A 2 (Modality) x 4 (Time) x 10 (Scales) mixed-ANOVA for the post-vigil data revealed a significant main effect for scales, F (5, 604) = 42.46, $p<.001$. While there were no significant overall effects for sensory modality or time on task ($p>.05$ in each case), there was a significant two-way interaction between scales and time, F (15, 604) = 2.64, $p<.01$ and a significant three-way interaction between scales, time, and modality, F(15, 604) = 2.11, $p<.01$.

In order to explore the three-way interaction more fully, separate Time x Modality between-groups ANOVAs were performed on the data of each DSSQ scale. No significant main effects or interactions were observed in regard to Energetic Arousal, Concentration, Self-Focused Attention, or Self-Esteem ($p>.05$ in each case). In the case of the Confidence and Control scale, the only significant effect was for time on task, F (3, 120) = 2.77, $p<.05$. As can be seen in Figure 6, observers' feelings of confidence and control declined over the course of the watch. In the case of the Motivation and Hedonic Tone scales, the only significant effect was for sensory modality, F (1, 120) >4.40, $p<.05$ in each case. Figure 6 reveals that observers in the visual condition reported themselves as feeling less motivated (M= -1.27) and less happy (M= -0.97) post-vigil than those in the auditory condition (M= -0.74 and -0.65, respectively). In the case of the Tense

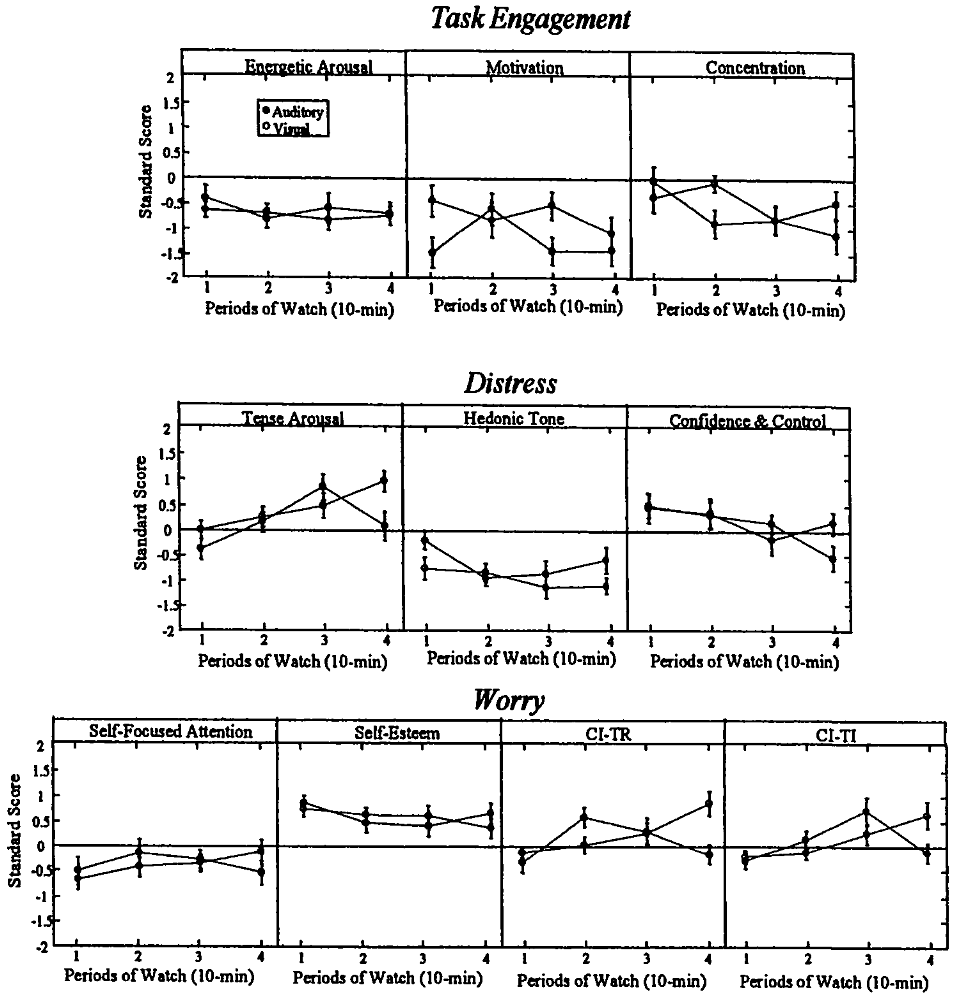

Figure 6. Post-vigil DSSQ scores as a function of periods of watch for the auditory and visual tasks. Error bars are standard errors. Note. CI-TR= Task-Related Cognitive Interference. CI-TI= Task-Irrelevant Cognitive Interference.

Arousal, Task-Related Cognitive Interference, and Task-Irrelevant Cognitive Interference scales, the scores increased significantly over time, F (3, 120) >3.59, $p<.05$ in each case, and the temporal change was modified significantly by the sensory modality of signals, $F_{Time \times Modality}$ (3, 120) >2.70, $p<.05$ in each case. Inspection of Figure 6 will reveal a similar pattern of changes over time in regard to Tense Arousal and both types of Cognitive Interference -- for these scales, the scores for the visual task increased monotonically over the course of the watch, while those for the auditory task followed an inverted-U function, increasing initially and then returning to their first period level by the end of the watch.

In sum, the *post*-vigil data reveal that the sensory channel used for stimulus delivery and the work time microstructure both have a significant impact upon the stress of sustained attention and that these effects are multidimensional in character. Some elements of the DSSQ were not influenced by these factors in the fine-grained analysis. For other scales, only time or modality had a significant effect upon feelings of task-induced stress, while for still other scales, signal modality was a moderator variable for the negative influence of time on watch. It is noteworthy that for some scales, Energetic Arousal, Motivation, Concentration, Hedonic Tone, Self-Focused Attention, and Self-Esteem, the pre-post changes observed at the coarse-grained level of analysis were not reflected in the temporal microstructure of the fine-grained analysis. Hence, for these scales the effect of time on task occurred early in the watch and remained constant thereafter.

CHAPTER IV
Discussion

The purpose of this study was to explore the effects of the sensory modality of signals and work time on performance efficiency in a vigilance task and on the dimensions of perceived mental workload and subjective stress which accompany vigilance performance. Essentially, the study was an effort to complete gaps in the tapestry of research on these dimensions of sustained attention. Both modality and time have been studied extensively with regard to performance efficiency. However, while temporal factors have been examined in regard to workload, sensory effects have been ignored and while sensory effects have been examined in regard to subjective stress, the possibility of systematic change over time has been ignored. In general, the results of this experiment provide additional support for the view that vigilance tasks present a major challenge to observers (Davies & Parasuraman, 1982; Warm & Dember, 1998; Warm, Dember, & Hancock, 1996; Parasuraman, Warm, & Dember, 1987), a challenge which is reflected in the complex roles that sensory and temporal factors play in performance efficiency, workload, and stress.

Performance. As is typical in vigilance studies, performance efficiency in terms of the probability of signal detections declined over time (cf. Davies & Parasuraman, 1982; See, Howe, Warm & Dember, 1995; Warm, 1984; 1993), and signal detectability was higher when observers were required to detect auditory as compared to visual signals, a result which is also consistent with several earlier findings (Baker, Ware, & Sipowicz, 1962; Buckner & McGrath, 1963; Colquhoun, 1975; Craig, Colquhoun, & Corcoran, 1976; Jones, & Kirk, 1970). While the results did not confirm reports by Sipowicz and Baker (1961) and Ware (1961) that the vigilance decrement is more pronounced in the case of visual than auditory signals, there was a trend in that direction.

It is noteworthy that in these two earlier studies time on task was a within-subjects variable while it was a between-subjects factor in this study. Hence, the absence of a significant Modality x Time interaction in the present case might reflect the diminished power associated with between-subjects designs.

The performance effects noted for modality in this investigation occurred even though the tasks were carefully equated for discrimination difficulty. Therefore, these effects are likely to be rooted in factors *other than* differential discrimination *per se*, such as the postural constraint, discomfort, and restlessness which arise from observers' efforts to compensate for the loosely-coupled nature of visual vigilance tasks (Galinsky, Rosa, Dember, & Warm, 1993; Hatfield & Loeb, 1968; Hunting, Laubli, & Grandjean, 1981), and the asthenopia and tension which have been found previously to be associated with the use of video display terminals (Dainoff, Happ, & Crane, 1981; Galinsky et al., 1993; Jaschinski-Kruza, 1991; Rey & Meyer, 1980).

Workload. To be sure, it was the possibility that observers in the visual condition would have to work through the combination of physical factors described above that led to the suspicion that perceived mental workload would be elevated for visual as compared to auditory monitoring. That suspicion, however, was not confirmed. Although, as in previous vigilance experiments (cf. Warm, Dember, & Hancock, 1996), global scores on the NASA-TLX indicated that the cost of mental operations in this study was substantial (the scores fell at the midpoint of the scale and exceeded those of a simple card-sorting task), the overall cost was similar for the visual and auditory modalities. Moreover, unlike the earlier findings of Dember et al. (1993), global workload did not increase significantly over time.

The absence of modality and time effects in the global workload scores represents a dissociation between workload and performance that is at variance with several prior studies in which performance changes associated with psychophysical manipulations were closely mirrored by variations in perceived workload (reviewed by Warm, Dember, & Hancock, 1996; see also Miller, Warm, Dember, & Schumsky, 1998). Such a dissociation is potentially important, since as Warm, Dember, and Hancock, 1996 have suggested, the ability to bring workload ratings under experimental control by demonstrating that factors which influence performance also affect workload is a key element in establishing the validity of such ratings in *vigilance*. Yeh and Wickens (1988) have made a similar argument in regard to a wide variety of other tasks.

Rather than challenging the validity of the global workload ratings, the modality component of the performance/workload dissociation might reveal subtle factors in the manner in which observers went about assessing workload in the present case. More specifically, it is conceivable that observers in this study based their workload ratings primarily upon an appraisal of the *signal discrimination* demands which confronted them rather than upon secondary physical factors, such as asthenopia and musculoskeletal fatigue, associated with the sensory channels carrying the signals to be detected.

An explanation of the modality component of the performance/workload dissociation in terms of processing mechanisms common to both modalities is based upon a theory of dissociation proposed by Yeh and Wickens (1988), in which performance/subjective workload dissociations are expected to occur when the tasks involved, while differing on some dimensions, have similar information processing or working memory demands. Along this line, it is important to note that together with the equation of signal discriminability in the auditory and visual channels at the outset of the study, both tasks required similar memory-based absolute judgments (or successive-type judgments, see Davies & Parasuraman, 1982; Warm & Dember, 1998) and the perceptual dimension to be discriminated - signal duration - was one that is based upon common audio-visual mechanisms (Eijkman & Vendrik, 1965; Loeb, Behar, & Warm, 1966; Warm, Stutz, & Vassolo, 1975). A signal discrimination explanation of the modality component of the performance/workload dissociation has two important implications. (1) It suggests that for the tasks employed herein, which feature a common central processor and similar working memory demands, the sensory channels used for stimulus presentation may not be critical factors in the workload of sustained attention. It remains to be determined, however, if workload similarities in auditory and visual vigilance tasks extend to cases in which the perceptual dimensions involved are not homologous within channels, such as brightness and loudness (Eijkman & Vendrik, 1965). (2) It would appear that a full account of the role of sensory factors in sustained attention requires a blend of workload and stress measures, since the latter may pick up the effects of factors, such as asthenopia and musculoskeletal fatigue, which might influence performance (see below) but whose effects may not be revealed in measures of perceived mental workload.

The temporal component of the performance/workload dissociation may also be related to the type of discriminations involved. A visual task requiring *spatial* discriminations with a scanning imperative was used in the study by Dember and his associates (1993) which revealed a growth in workload over time, whereas *temporal* discriminations, which did *not* require observers to scan visual or auditory space, were employed herein. It is possible that the differing demands imposed by environmental scanning could have led to the temporal changes noted in the early study as compared to this one.

Although the global workload scores in this study remained stable over time, a clear temporal change was observed with the Frustration subscale of the NASA-TLX -- frustration increased linearly over time. Dember and his associates (1993) also observed a significant rise in frustration with time on task. One might wonder about the trigger for such an effect. A possible explanation may lie in the resource model of vigilance performance. Parasuraman and his associates (Davies & Parasuraman, 1982; Parasuraman, Warm, & Dember, 1987) have argued that because of the need to make continuous signal/noise discriminations, the performance decrement reflects the depletion of information-processing resources that cannot be replenished in the time available. This argument has been supported by the finding that cerebral bloodflow declines over time in a manner paralleling the performance decrement (Mayleben, Warm, Dember, Rosa, Shear, Temple, & Parasuraman, 1998). In addition, Yeh and Wickens (1988) have suggested that the inability to summon resources leads to increased frustration. Hence, the decrement in performance and the increment in frustration may originate from a common process -- the decline of resource availability with time on watch.

In addition to resource depletion, the expectancies observers have regarding the task and their feelings about their efforts to manage their interaction with the task may also have contributed to the rise in frustration over time. According to Hart and Staveland (1988), the Frustration scale of the TLX provides information concerning how comfortable operators feel about the effectiveness of their efforts to handle the task with which they are confronted. Since observers engaged in vigilance tasks typically begin the watch by overestimating critical signal probability and lower their expectations regarding the frequency of appearance of signals as they gain more experience with the task (Craig, 1978; Williges, 1969), it is possible that the temporal rise in frustration indicates a growing realization on the part of the observers that the targets they were seeking were rare and that their observing activities were not likely to be extremely fruitful. Given such a temporally based change in the Frustration subscale, one might also wonder why there was no concomitant change in the global workload scores. As described by Hart and Staveland (1988), the Frustration subscale is one of six independent subscales which contribute to global workload on the TLX. Thus, its contribution to the temporal characteristics of the global score could have been minimized by the results of the other scales which remained stable over time.

Along with the finding of increased frustration over time, Frustration and Mental Demand emerged as the principal contributors to workload in the present study. The latter outcome is consistent with that of many previous investigations and indicates that there may be a typical workload profile or signature that reflects the particular demands imposed by vigilance tasks (Becker, Warm, Dember, & Hancock, 1991; Warm, Dember, & Hancock, 1996). According to Eggemeier and his associates (Eggemeier, Wilson, Kramer, & Damos, 1991; Eggemeier & Wilson, 1991; O'Donnell & Eggemeier, 1986), *diagnosticity*, or the ability of a measure to provide information about component factors in workload, is an important property of workload assessment techniques. Given the findings regarding the gain in frustration over time and the role of Frustration and Mental Demand as the principal contributors to workload, the results of this study join those of several other vigilance studies in testifying to the ability of the TLX to meet the diagnosticity requirement.

Stress. As noted earlier, one of the reasons for using the DSSQ to measure subjective stress in this investigation was because it permits the assessment of stress as a multidimensional construct. The multidimensional nature of stress was revealed by findings at both the coarse-grained and fine-grained levels of analysis which showed that the DSSQ scales were not uniform in the pattern in which observers responded to having participated in the vigil. At the coarse-grained level of analysis, the scores indicated that observers found the vigil to be quite stressful. They reported themselves as being less task engaged and more distressed after the vigil than prior to its start. However, participation in the vigil had little impact upon their feelings of worry. These results are consistent with those of prior studies using the DSSQ to assess the stress of sustained attention (Grier et al., 1999; Helton et al., in press; Matthews et al., 1999; Temple et al., in press) and with a study by Matthews and his associates on a driving simulation task in which vigilance was a part (Matthews, Campbell, Desmond, Huggins, Falconer, & Joyner, 1998).

As described by Matthews (Matthews, in press, Matthews & Campbell, 1998), a key insight into stress and performance is that operators actively regulate their handling of task demands in stressful environments by the use of different coping strategies. Included are *task- or problem-focused coping* in which actions are directed toward changing external reality, *emotion-focused coping* which is designed to alter the way in which the operator thinks or feels about the source of stress, and *avoidance-coping* in which operators divert attention away from the task. Apparently all three coping strategies were operative in the efforts of the present observers to come to terms with the stress of sustained attention, since a decrease in task engagement, such as that noted in this study, implies a loss of problem-focused coping (Matthews & Campbell, 1998), while an increase in distress implies use of emotion-coping, and to a lesser extent, avoidance-coping styles (Matthews, et al. 1999). In addition, it is noteworthy that Matthews and his associates (Matthews, et al., 1999) have reported significant correlations between the DSSQ dimension of Distress and both the diffuse measure of overall workload on the TLX and the focal index of Frustration. Such linkage between workload and stress should not be surprising, however, since stress has been considered to be a component of workload on both the NASA-TLX (Hart & Staveland, 1988) and another major scale of mental workload, The Subjective Workload Assessment Technique (SWAT, Reid & Nygren, 1988).

The roles of the sensory modality of signals and time at work on observers' stress reports in this study were revealed through the fine-grained analysis of the DSSQ scales. As in the case of the coarse-grained analysis, the fine-grained analysis revealed that the reports of stress were not uniform across scales. Some of the scales, such as Energetic Arousal, Concentration, Self-Focused Attention, and Self-Esteem showed no effects for modality or time over the course of the watch. Others, such as Motivation and Hedonic Tone showed that observers were uniformly more stressed in the visual than in the auditory condition throughout the vigil but showed no systematic changes in the levels of stress over time. Still other scales, Confidence and Control, Tense Arousal, Task-Related Cognitive Interference, and Task-Irrelevant Cognitive Interference showed increments in stress with time on watch, and in the case of the latter three scales, the temporal effect was modified by stimulus modality. Clearly, stress changes are not uniform in their temporal microstructure, a result which was masked in the many earlier studies of the stress of sustained attention described in Chapter 1 which only focused upon pre-post vigil differences.

The diffuse pattern of changes on the DSSQ scales to the stress of sustained attention reaffirms the notion that stress states require multidimensional description (Hockey, 1984). Unfortunately, a general theory of stress which can encompass this complex pattern of results is not currently available (Matthews, in press). However, some insight as to the meaning of these findings may be gained by viewing them from the perspective of coping strategies and the transactional model (Lazarus & Folkman, 1984; Matthews, in press), which suggests that the extent to which specific coping strategies are adopted varies dynamically with the person-environment transaction. For example, the temporal decline in confidence and control may, as in the case of the rise of frustration on the TLX, reflect the inability of observers to replenish their processing resources, or to generate task-focused strategies which would enable them to counter their growing awareness over time that the targets they were looking or listening for were of low probability.

In a similar vein, the finding of modality-moderated changes over time in regard to the Tense Arousal scale and both Cognitive Interference Scales, in which stress increased monotonically over the course of the vigil for visual signals but followed an inverted-U shaped function for auditory signals (increased stress during the early portion of the vigil followed by a return to baseline), may also reflect differences in the development of effective coping strategies. As Hancock and Warm (1989) and Matthews (in press) have pointed out, the implementation of coping strategies requires information-processing resources. The need to handle the disrupting physical factors uniquely associated with visual displays, such as asthenopia and musculoskeletal fatigue, may serve to drain resources from the development of adaptive coping strategies in the visual modality. In contrast, observers in the auditory condition, who were free of these physical problems, were more successful in their efforts to cope with the tension and cognitive interference associated with the task. The declines in Distress (Tense Arousal) and Worry (both types of Cognitive Interference) which suggest a shift away from emotion-focused coping, indicate that by the end of the experimental session, the vigilance task, although generally unpleasant and frustrating, was no longer threatening or disturbing to observers in the auditory condition (see Matthews et al., 1999).

In sum, the findings of this experiment show that the subjective reports of stress in sustained attention tasks grow over time, and they confirm the report by Galinsky et al. (1993) that a major psychophysical variable which affects signal detection, the sensory modality of signals, also impacts the stress of vigilance. They indicate, however, that these effects are complex in nature and show up differently when different stress dimensions and sensory modalities are considered. Taken together with the TLX Frustration results, the DSSQ findings indicate that in order to minimize operator stress, an important consideration in the modern workplace (Nickerson, 1992; Sauter, Murphy, & Hurrell, 1990), display modality and time on task should be critical components in the design of systems and operations which include vigilance functions.

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APPENDIX A:

THE NASA TASK LOAD INDEX

&

DUNDEE STRESS STATE QUESTIONNAIRE

NASA-TLX Instructions

Part I

Rating Scales. We are not only interested in assessing your performance but also the experiences you had during the experiment. In the most general sense, we are examining the "workload" you experienced. Workload is a difficult concept to define precisely but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put into it, or the stress and frustration you felt. In addition, the workload contributed by different task elements may change as you become more familiar with the task. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to assess.

Since workload is something that is experienced individually by each person, there are no set "rulers" that can be used to estimate the workload associated with different activities. One way to find out about workload is to ask people to describe the feelings they experienced while performing a task. Because workload may be caused by different factors, we would like you to evaluate several of them individually rather than by lumping them into a single, global evaluation of overall workload. This set of six rating scales [HAND THE DESCRIPTIONS TO THE PARTICIPANT] was developed for you to use in evaluating your experiences during this task. Please read the descriptions of the scales carefully. If you have any questions about any of the scales in the table, please ask me about them. It is extremely important that they be clear to you. You may keep the descriptions with you for reference while completing the scales.

[ALLOW THE PARTICIPANT TO READ THROUGH THE DESCRIPTIONS NOW]

For each of the six scales, you will evaluate the task by typing in a multiple of 5 that can range from 0 to 100 to reflect the point that matches your experience. Pay close attention to each scale's endpoint description when making your assessments. Note that when the rating scale for PERFORMANCE appears, the scale will go from "good" on the *left* to "bad" on the *right*. This means that a *low* number will represent good performance, while a *high* number will signify poor performance. This order has been confusing for some people. Upon completing each scale, press the "return" key to go on to the next one. Read the description for each scale again before making your rating.

NASA-TLX Instructions

Part II

Pairwise Comparisons. Rating scales of this sort are extremely useful, but their utility is diminished by the tendency people have to interpret them in different ways. For example, some people feel that mental or temporal demands are the greatest contributors to workload regardless of the effort they expended in performing a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low; and if they performed poorly, then it must have been high. Still others believe that effort or feelings of frustration are the most important determinants of their experiences of workload. Previous studies using this scale have found several different patterns of results. In addition, the factors that determine workload differ depending on the task. For instance, some tasks might be difficult because they must be completed very quickly. Other tasks may seem easy or hard because the degree of mental or physical effort required. Some task may seem difficult because they cannot be performed well no matter how much effort is expended.

The next step in your evaluation is to assess the relative importance of the six factors in determining how much workload you experienced. You will be presented with pairs of rating scale titles (e.g. EFFORT vs. MENTAL DEMAND) and asked to choose which of the two items was more important to your experience of workload in the task that you just performed. Each pair of scale titles will appear separately on the video screen. Type in "1" if the uppermost scale title in the pair represents the more important contributor to the workload of the task. Type in "2" if the lower scale title in a pair represents the more important contributor to workload. After indicating your response to a pair of scale titles, press the "return" key to go on to the next pair.

Please consider your choices carefully and try to make them consistent with your scale ratings. Refer back to the rating scale definitions if you need to as you proceed. There is no correct pattern of responses. We are only interested in your opinions.

Do you have any questions?

RATING SCALE DEFINITIONS

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	GOOD/POOR	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	LOW/HIGH	How insecure, discouraged, irritated stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

STATE QUESTIONNAIRE[1]

General Instructions. This questionnaire is concerned with your feelings and thoughts at the moment. We would like to build up a detailed picture of your current state of mind, so there are quite a few questions, divided into four sections. Please answer every question, even if you find it difficult. Answer, as honestly as you can, what is true of you. Please do not choose a reply just because it seems like the 'right thing to say'. Your answers will be kept entirely confidential. Also, be sure to answer according to how you feel **AT THE MOMENT**. Don't just put down how you usually feel. You should try and work quite quickly: there is no need to think very hard about the answers. The first answer you think of is usually the best.

Before you start, please provide some general information about yourself.

Age............ (years)	Sex. M F (Circle one)
Occupation..
If student, state your course..................................
Date today....................	Time of day now.............

1. MOOD STATE

First, there is a list of words which describe people's moods or feelings. Please indicate how well each word describes how you felt **AT THE MOMENT**. For each word, circle the answer from 1 to 4 which best describes your mood.

	Definitely	Slightly	Slightly Not	Definitely Not
1. Happy	1	2	3	4
2. Dissatisfied	1	2	3	4
3. Energetic	1	2	3	4
4. Relaxed	1	2	3	4
5. Alert	1	2	3	4
6. Nervous	1	2	3	4
7. Passive	1	2	3	4
8. Cheerful	1	2	3	4
9. Tense	1	2	3	4
10. Jittery	1	2	3	4
11. Sluggish	1	2	3	4
12. Sorry	1	2	3	4
13. Composed	1	2	3	4
14. Depressed	1	2	3	4
15. Restful	1	2	3	4
16. Vigorous	1	2	3	4
17. Anxious	1	2	3	4
18. Satisfied	1	2	3	4
19. Unenterprising	1	2	3	4
20. Sad	1	2	3	4
21. Calm	1	2	3	4
22. Active	1	2	3	4
23. Contented	1	2	3	4

[1] Pre-task version

24. Tired	1	2	3	4
25. Impatient	1	2	3	4
26. Annoyed	1	2	3	4
27. Angry	1	2	3	4
28. Irritated	1	2	3	4
29. Grouchy	1	2	3	4

2. MOTIVATION

Please answer the following questions about your attitude to the task you are about to do. For each question, circle a number from 0 to 9, according to how strongly you agree with one or other of the two extreme alternatives.

1. How motivated are you to do the task?
Not at all   Very much
0 1 2 3 4 5 6 7 8 9

2. Do you think the content of the task is:
Very dull   Very interesting
0 1 2 3 4 5 6 7 8 9

3. How eager are you to do well at the task?
Very eager   Not at all eager
0 1 2 3 4 5 6 7 8 9

4. How do you expect to feel after doing the task?
More cooperative   More annoyed
0 1 2 3 4 5 6 7 8 9

5. How much mental effort will you exert?
Very little   A great deal
0 1 2 3 4 5 6 7 8 9

6. I want to succeed on this task:
Very much   Very little
0 1 2 3 4 5 6 7 8 9

7. How will you feel if you perform badly on this task?
Very unconcerned   Very upset
0 1 2 3 4 5 6 7 8 9

8. I think that doing this task will be:
Very worthwhile   A waste of time
0 1 2 3 4 5 6 7 8 9

3. THINKING STYLE

In this section, we are concerned with your thoughts about yourself: how your mind is working, how confident you feel, and how well you expect to perform on the task. Below are some statements which may describe your style of thought **RIGHT NOW**. Read each one carefully and indicate how true each statement is of your thoughts **AT THE MOMENT**. To answer, circle one of the following answers: Extremely = 4 Very much = 3 Somewhat = 2 A little bit = 1 Not at all = 0

1.	I'm trying to figure myself out.	0	1	2	3	4
2.	I'm very aware of myself.	0	1	2	3	4
3.	I'm reflecting about myself.	0	1	2	3	4
4.	I'm daydreaming about myself.	0	1	2	3	4
5.	I'm thinking deeply about myself.	0	1	2	3	4
6.	I'm attending to my inner feelings.	0	1	2	3	4
7.	I'm examining my motives.	0	1	2	3	4
8.	I feel that I'm off somewhere watching myself.	0	1	2	3	4
9.	I feel confident about my abilities.	0	1	2	3	4
10.	I am worried about whether I am regarded as a success or failure.	0	1	2	3	4
11.	I feel self-conscious.	0	1	2	3	4
12.	I feel as smart as others.	0	1	2	3	4
13.	I am worried about what other people think of me.	0	1	2	3	4
14.	I feel confident that I understand things.	0	1	2	3	4
15.	I feel inferior to others at this moment.	0	1	2	3	4
16.	I feel concerned about the impression I am making.	0	1	2	3	4
17.	I feel that I have less scholastic ability right now than others.	0	1	2	3	4
18.	I am worried about looking foolish.	0	1	2	3	4
19.	My attention is directed towards things other than the task.	0	1	2	3	4
20.	I am finding physical sensations such as muscular tension distracting.	0	1	2	3	4
21.	I expect my performance will be impaired by thoughts irrelevant to the task.	0	1	2	3	4
22.	I have too much to think about to be able to concentrate on the task.	0	1	2	3	4
23.	My thinking is generally clear and sharp.	0	1	2	3	4
24.	I will find it hard to maintain my concentration for more than a short time.	0	1	2	3	4
25.	My mind is wandering a great deal.	0	1	2	3	4
26.	My thoughts are confused and difficult to control.	0	1	2	3	4
27.	I expect to perform proficiently on this task.	0	1	2	3	4
28.	Generally, I feel in control of things.	0	1	2	3	4

4. THINKING CONTENT

This set of questions concerns the kinds of thoughts that go through people's heads at particular times, for example while they are doing some task or activity. Below is a list of thoughts, some of which you might have had recently. Please indicate roughly how often you had each thought DURING THE LAST TEN MINUTES or so, by circling a number from the list below.

1= Never 2= Once 3= A few times 4= Often 5= Very often

1.	I thought about how I should work more carefully.	1 2 3 4 5
2.	I thought about how much time I had left.	1 2 3 4 5
3.	I thought about how others have done on this task.	1 2 3 4 5
4.	I thought about the difficulty of the problems.	1 2 3 4 5
5.	I thought about my level of ability.	1 2 3 4 5
6.	I thought about the purpose of the experiment.	1 2 3 4 5
7.	I thought about how I would feel if I were told how I performed.	1 2 3 4 5
8.	I thought about how often I get confused.	1 2 3 4 5
9.	I thought about members of my family.	1 2 3 4 5
10.	I thought about something that made me feel guilty.	1 2 3 4 5
11.	I thought about personal worries.	1 2 3 4 5
12.	I thought about something that made me feel angry.	1 2 3 4 5
13.	I thought about something that happened earlier today.	1 2 3 4 5
14.	I thought about something that happened in the recent past (last few days, but not today).	1 2 3 4 5
15.	I thought about something that happened in the distant past	1 2 3 4 5
16.	I thought about something that might happen in the future.	1 2 3 4 5

STATE QUESTIONNAIRE[2]

General Instructions

This questionnaire is concerned with your feelings and thoughts while you were performing the task. We would like to build up a detailed picture of your current state of mind, so there are quite a few questions, divided into four sections. Please answer every question, even if you find it difficult. Answer, as honestly as you can, what is true of you. Please do not choose a reply just because it seems like the 'right thing to say'. Your answers will be kept entirely confidential. Also, be sure to answer according to how you felt **WHILE PERFORMING THE TASK.** Don't just put down how you usually feel. You should try and work quite quickly: there is no need to think very hard about the answers. The first answer you think of is usually the best.

1. MOOD STATE

First, there is a list of words which describe people's moods or feelings. Please indicate how well each word describes how you felt **WHILE PERFORMING THE TASK.** For each word, circle the answer from 1 to 4 which best describes your mood.

	Definitely	Slightly	Slightly Not	Definitely Not
1. Happy	1	2	3	4
2. Dissatisfied	1	2	3	4
3. Energetic	1	2	3	4
4. Relaxed	1	2	3	4
5. Alert	1	2	3	4
6. Nervous	1	2	3	4
7. Passive	1	2	3	4
8. Cheerful	1	2	3	4
9. Tense	1	2	3	4
10. Jittery	1	2	3	4
11. Sluggish	1	2	3	4
12. Sorry	1	2	3	4
13. Composed	1	2	3	4
14. Depressed	1	2	3	4
15. Restful	1	2	3	4
16. Vigorous	1	2	3	4
17. Anxious	1	2	3	4
18. Satisfied	1	2	3	4
19. Unenterprising	1	2	3	4
20. Sad	1	2	3	4
21. Calm	1	2	3	4
22. Active	1	2	3	4
23. Contented	1	2	3	4
24. Tired	1	2	3	4
25. Impatient	1	2	3	4
26. Annoyed	1	2	3	4
27. Angry	1	2	3	4

[2] Post-task version

28. Irritated	1	2	3	4
29. Grouchy	1	2	3	4

2. MOTIVATION AND WORKLOAD

Please answer the following questions about your attitude to the task you have just done. For each question, circle a number from 0 to 9, according to how strongly you agree with one or other of the two extreme alternatives.

1. How motivated were you to do the task?
Not at all — Very much
0 1 2 3 4 5 6 7 8 9

2. Do you think the content of the task was:
Very dull — Very interesting
0 1 2 3 4 5 6 7 8 9

3. How eager were you to do well at the task?
Very eager — Not at all eager
0 1 2 3 4 5 6 7 8 9

4. How do you feel after doing the task?
More cooperative — More annoyed
0 1 2 3 4 5 6 7 8 9

5. How much mental effort did you exert?
Very little — A great deal
0 1 2 3 4 5 6 7 8 9

6. I wanted to succeed on this task:
Very much — Very little
0 1 2 3 4 5 6 7 8 9

7. How would you feel if you performed badly on this task?
Very unconcerned — Very upset
0 1 2 3 4 5 6 7 8 9

8. I think that doing this task was:
Very worthwhile — A waste of time
0 1 2 3 4 5 6 7 8 9

9. Please rate the MENTAL DEMAND of the task: How much mental and perceptual activity was required?
Low 0 1 2 3 4 5 6 7 8 9 10 High

10. Please rate the PHYSICAL DEMAND of the task: How much physical activity was required?
Low 0 1 2 3 4 5 6 7 8 9 10 High

11. Please rate the TEMPORAL DEMAND of the task: How much time pressure did you feel due to the pace at which the task elements occurred?
Low 0 1 2 3 4 5 6 7 8 9 10 High

12. Please rate your PERFORMANCE: How successful do you think you were in accomplishing the goals of the task?
Low 0 1 2 3 4 5 6 7 8 9 10 High

13. Please rate your EFFORT: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low 0 1 2 3 4 5 6 7 8 9 10 High

14. Please rate your FRUSTRATION: How discouraged, irritated, stressed and annoyed did you feel during the task?

Low 0 1 2 3 4 5 6 7 8 9 10 High

3. THINKING STYLE

In this section, we are concerned with your thoughts about yourself: how your mind is working, how confident you feel, and how well you believed you performed on the task. Below are some statements which may describe your style of thought during task performance. Read each one carefully and indicate how true each statement was of your thoughts **WHILE PERFORMING THE TASK**. To answer circle one of the following answers: Extremely = 4 Very much = 3 Somewhat = 2 A little bit = 1 Not at all = 0

1.	I tried to figure myself out.	0 1 2 3 4
2.	I was very aware of myself.	0 1 2 3 4
3.	I reflected about myself.	0 1 2 3 4
4.	I daydreamed about myself.	0 1 2 3 4
5.	I thought deeply about myself.	0 1 2 3 4
6.	I attended to my inner feelings.	0 1 2 3 4
7.	I examined my motives.	0 1 2 3 4
8.	I felt that I was off somewhere watching myself.	0 1 2 3 4
9.	I felt confident about my abilities.	0 1 2 3 4
10.	I was worried about whether I am regarded as a success or failure.	0 1 2 3 4
11.	I felt self-conscious.	0 1 2 3 4
12.	I felt as smart as others.	0 1 2 3 4
13.	I was worried about what other people think of me.	0 1 2 3 4
14.	I felt confident that I understood things.	0 1 2 3 4
15.	I felt inferior to others.	0 1 2 3 4
16.	I felt concerned about the impression I was making.	0 1 2 3 4
17.	I felt that I had less scholastic ability than others.	0 1 2 3 4
18.	I was worried about looking foolish.	0 1 2 3 4
19.	My attention was directed towards things other than the task.	0 1 2 3 4
20.	I found physical sensations such as muscular tension distracting.	0 1 2 3 4
21.	My performance was impaired by thoughts irrelevant to the task.	0 1 2 3 4
22.	I had too much to think about to be able to concentrate on the task.	0 1 2 3 4
23.	My thinking was generally clear and sharp.	0 1 2 3 4
24.	I found it hard to maintain my concentration for more than a short time.	0 1 2 3 4
25.	My mind wandered a great deal.	0 1 2 3 4
26.	My thoughts were confused and difficult to control	0 1 2 3 4
27.	I performed proficiently on this task.	0 1 2 3 4
28.	Generally, I felt in control of things.	0 1 2 3 4

4. THINKING CONTENT

This set of questions concerns the kinds of thoughts that go through people's heads at particular times, for example while they are doing some task or activity. Below is a list of thoughts, some of which you might have had recently. Please indicate roughly how often you had each thought during **THE LAST TEN MINUTES** (while performing the task), by circling a number from the list below.

1= Never 2= Once 3= A few times 4= Often 5= Very often

1.	I thought about how I should work more carefully.	1 2 3 4 5
2.	I thought about how much time I had left.	1 2 3 4 5
3.	I thought about how others have done on this task.	1 2 3 4 5
4.	I thought about the difficulty of the problems.	1 2 3 4 5
5.	I thought about my level of ability.	1 2 3 4 5
6.	I thought about the purpose of the experiment.	1 2 3 4 5
7.	I thought about how I would feel if I were told how I performed.	1 2 3 4 5
8.	I thought about how often I get confused.	1 2 3 4 5
9.	I thought about members of my family.	1 2 3 4 5
10.	I thought about something that made me feel guilty.	1 2 3 4 5
11.	I thought about personal worries.	1 2 3 4 5
12.	I thought about something that made me feel angry.	1 2 3 4 5
13.	I thought about something that happened earlier today.	1 2 3 4 5
14.	I thought about something that happened in the recent past (last few days, but not today).	1 2 3 4 5
15.	I thought about something that happened in the distant past	1 2 3 4 5
16.	I thought about something that might happen in the future.	1 2 3 4 5

DUNDEE STRESS STATE QUESTIONNAIRE: v 1.2

Scoring

This questionnaire comprises a mixture of existing scales and items for important stress-related constructs which are not well measured by other questionnaires. The v 1.2 scales are based on factor analyses of data from 449 subjects who completed an initial pre-task measure and 694 subjects who completed a post-task questionnaire (including the 449..). Items were selected for scales only if they loaded substantially on the same factors in the pre- and post-task factor solutions. No more than 8 items were selected for each scale. Scoring of self-esteem and control scales is significantly modified, with respect to the previous version. Some of the other scales now have reduced numbers of items, and minor changes have been made to scale names. The DSSQ includes both monopolar and bipolar scales, which are scored as follows. For the monopolar scales (i.e. all items scored the same way) simply add up all the individual item scores. In two cases, the sum of the item scores is subtracted from a constant, so that high scores match the scale name appropriately.

For bipolar scales (positive and negative items), 'reverse-scored' item scores must be recalculated before item scores are summated.

Mood and affect

Part 1 of the questionnaire is the UWIST Mood Adjective Checklist (Matthews et al., 1990), for which there is quite a bit of psychometric and validation data. The Energy, Tension and Hedonic Tone scales are supported by item factor analysis. Anger/Frustration items load on the Hedonic Tone scale, but in some contexts it is useful to have a separate anger measure. Items are as follows:

Energetic arousal: 3, 5, 16, 22 (positive items), 7, 11, 19, 24 (negative items)

Tense arousal: 6, 9, 10, 17 (pos.), 4, 13, 15, 21 (neg.)

Hedonic tone: 1, 8, 18, 23 (pos.), 2, 12, 14, 20 (neg.)

Anger/frustration: 25, 26, 27, 28, 29 (pos.)

On the UMACL, it is the positive items which are reverse-scored. To do this, subtract the item score from 5. e.g., to score the Energetic Arousal score, take the scores on items 3, 5, 16 and 22, and subtract each one from 5. Then add together all eight item scores to get the scale score.

Motivation

Items 1-8 of Part 2 of the questionnaire measures a single dimension of task motivation or intrinsic motivation: items 1, 2, 5 and 7 are positively scored (high motivation), whereas 3, 4, 6 and 8 are negatively scored (low motivation). Items 9-14 on the post-task questionnaire assess workload, and comprise the NASA-TLX questionnaire (Hart & Staveland, 1988).

On the motivation scale, the negative items are reverse-scored. Subtract each negatively-scored item score from 9 prior to summation. Workload is unipolar.

Cognitive state

Part 3 of the questionnaire ('Thinking Style') assesses the person's general style of thinking and beliefs about the task, whereas Part 4 assesses specific intruding thoughts. Part 3 includes items generated by modifying Fenigstein et al.'s (1975) measure of private self-consciousness or self-focus of attention to give state items similar to that used by Sedikides (1992). Self-focus is believed to be increased in states of stress. It also includes items from Heatherton and Polivy's (1991) self-esteem scales, and new items relating to concentration and perceived control over the performance environment.

Scale are scored as follows. All scales are monopolar.

Self-focused Attention. (8 items). This scale comprises selected items from the modified Fenigstein et al. (1975) private self-consciousness scale. Summate item scores on items 1-8.

Self-esteem. (7 items). This scale comprises 6 social self-esteem and 1 performance self-esteem items from the Heatherton and Polivy (1991) questionnaire, and may be seen as a general self-esteem scale. Summate items 10, 11, 13, 15, 16, 17 and 18 and subtract total from 28. (This step ensures high scores indicate high esteem).

Concentration (7 items). This scale comprises most of the items written to represent perceived efficiency of attention. Summate items 19-22 and 24-26 and subtract total from 28. High scores indicate good concentration.

Control and Confidence (6 items). This scale is made up mainly of positive performance self-esteem items, relating to confidence, and perceived control items. (The perceived control and performance self-esteem constructs appear to overlap). Summate items 9, 12, 14, 23, 27 and 28.

Part 4 ('Thinking Content') comprises items from Sarason et al.'s (1986) Cognitive Interference Questionnaire (CIQ). Following factor analysis of the initial questionnaire some CIQ items are omitted from v 1.2 . Eight-item scales have been devised on the basis of the factor analysis:

Task-related interference (8 items). Summate scores on items 1-8.

Task-irrelevant interference (8 items). Summate scores on items 9-16.

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Fenigstein, A., Scheier, M.F., & Buss, A.H. (1975) Public and private self-consciousness: Assessment and theory. *Journal of Consulting and Clinical Psychology, 43,* 522-527.

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APPENDIX B:

INSTRUCTIONS FOR THE CROSS MODALITY MATCHING PROCEDURE AND THE SUSTAINED ATTENTION TASKS

Cross-Modality Matching Procedure

Before we begin some measurements have to be made.

You will see a bar of light on the screen in front of you and you will hear a burst of noise in your headphones. As I adjust the intensity of the noise, I want you to tell me when it seems to you that the noise is as loud as the light is bright. There are no right or wrong answers. I am only interested in determining when the noise seems as loud to you as an individual as the light is bright.

Sustained Attention Task Instructions: Auditory Condition

In this study we are interested in how well people can detect changes in the duration of a burst of noise. Your task during this portion of the experiment will be to listen to bursts of noise that will be presented at a fairly rapid rate. Normally, the bursts will last a certain period of time. These are neutral events, and you do not need to respond. Occasionally, however, the duration of the bursts will be shorter than normal. These are critical signals for detection. Whenever you think the duration of the sound has been shorter than normal, you are to press the key marked "SIG" on the keypad. Please do not respond indiscriminately, however, because this may lower your score.

Please press the "SIG" key.

In order to familiarize you with how long the bursts of noise will normally last, the next 10 events will be bursts that are longer in duration.

Please press the "SIG" key on the keypad.

[Exposure to signals]

The next 10 events are examples of bursts of noise that are shorter in duration. These will be the critical signals for detection.

Please press the "SIG" key on the keypad.

[Exposure to signals]

You will now hear the bursts of noise in pairs. The burst of longer duration, which is the neutral event, will be presented first in each pair.

Please press the "SIG" key on the keypad.

[Exposure to signals]

Remember, whenever you think you've heard a critical signal, you are to respond by pressing the key marked "SIG" on the keypad, but please don't respond indiscriminately because this may lower your score. Do you have any questions?

You will now begin a brief practice session. Remember, your task is to detect brief bursts of noise in a stream of longer bursts. Press the "SIG" key when you are ready to begin, but please wait until the experimenter has left the booth.

[5-min practice]

At the end of the practice session, the participant receives the following instructions:

The practice session has ended. Please notify the experimenter that you are finished with this part of the experiment. Please do not touch the computer while you are waiting.

The above instructions for the practice session are repeated if a second practice session is needed.

The time perception task will now begin. Remember, your task is to respond by pressing the key marked "SIG" on the keypad whenever you think you have heard a critical signal, but do not respond indiscriminately, because this may lower your score. Do you have any questions?

Press the "SIG" key on the key pad when you are ready to begin.

When the vigil is completed, the following instructions appear on the screen:

Please notify the experimenter that you are finished with this part of the experiment.

Please do not touch the computer while you are waiting.

Sustained Attention Task Instructions: Visual Condition

In this study we are interested in how well people can detect changes in the duration of a flash of light. Your task during this portion of the experiment will be to monitor the screen in front of you. You will see a white horizontal bar in the center of the screen that will be flashed on and off at a fairly rapid rate. Normally, the white bar will be on the screen for a certain period of time. These are neutral events, and you do not need to respond. Occasionally, however, the white bar will be on the screen for a shorter period of time. These are critical signals for detection. Whenever you think the bar has been on the screen for a shorter time than normal, you are to press the key marked "SIG" on the keypad. Please do not respond indiscriminately, however, because this may lower your score.

Please press the "SIG" key.

In order to familiarize you with how long the flashes of the bar will normally last, the next 10 events will be flashes that are longer in duration.

Please press the "SIG" key on the keypad.

[Exposure to signals]

The next 10 events are examples of flashes of the bar that are shorter in duration. These will be the critical signals for detection.

Please press the "SIG" key on the keypad.

[Exposure to signals]

You will now see the flashes of the bar in pairs. The flash of longer duration, which is the neutral event, will be presented first in each pair.

Please press the "SIG" key on the keypad.

[Exposure to signals]

Remember, whenever you think you've seen a critical signal, you are to respond by pressing the key marked "SIG" on the keypad, but please don't respond indiscriminately because this may lower your score. Do you have any questions?

You will now begin a brief practice session. Remember, your task is to detect brief flashes of light in a stream of longer flashes. Press the "SIG" key when you are ready to begin, but please wait until the experimenter has left the booth.

[5-min practice]

At the end of the practice session, the participant receives the following instructions:

The practice session has ended. Please notify the experimenter that you are finished with this part of the experiment. Please do not touch the computer while you are waiting.

The above instructions for the practice session are repeated if a second practice session is needed.

The time perception task will now begin. Remember, your task is to respond by pressing the key marked "SIG" on the keypad whenever you think you have seen a critical signal, but do not respond indiscriminately, because this may lower your score.
Do you have any questions?

Press the "SIG" key on the keypad when you are ready to begin.

When the vigil is completed, the following instructions appear on the screen:

Please notify the experimenter that you are finished with this part of the experiment.

Please do not touch the computer while you are waiting.

APPENDIX C:

SUMMARY TABLES OF STATISTICAL ANALYSES

Table C1.

Analysis of Variance for correct detection scores

Source	df	MS	F	p
Modality (A)	1	20.182	60.24*	<.001
Time (B)	3	5.006	14.94*	<.001
A x B	3	0.557	1.66	>.05
S/G	248	0.335		

Table C2.

Analysis of Variance for false alarm scores

Source	df	MS	F	p
Modality (A)	1	0.072	2.48	>.05
Time (B)	3	0.019	0.66	>.05
A x B	3	0.010	0.34	>.05
S/G	248	0.029		

Table C3.

Analysis of Variance for NASA-TLX global workload scores

Source	df	MS	F	p
Modality (A)	1	265.458	0.60	>.05
Time (B)	3	291.682	0.66	>.05
A x B	3	246.075	0.55	>.05
S/G	120	444.430		

Table C4.

Analysis of Variance for NASA-TLX weighted subscale ratings

Source	df	df_{adj}	MS	F	p
Between Subjects	127	---			
Modality (A)	1	---	16150.352	0.84	>.05
Time (B)	3	---	8356.393	0.44	>.05
AB	3	---	10548.268	0.55	>.05
S/G	120	---	19126.388		
Within Subjects	512				
Subscales (C)	4	3	170647.227	14.75	<.001
AC	4	3	9457.578	0.82	>.05
BC	12	10	23416.680	2.02	<.05
ABC	12	10	15266.302	1.32	>.05
C x S/G	480	417	11569.969		

Note. df_{adj} = degrees of freedom obtained when Box's ε is used to correct for violations of sphericity. Box's $\varepsilon = 0.87$

Table C5.

Analysis of Variance for NASA-TLX Weighted ratings: Mental Demand

Source	df	MS	F	p
Time	3	13895.052	0.78	>.05
S/G	124	17825.769		

Table C6.

Analysis of Variance for NASA-TLX Weighted ratings: Temporal Demand

Source	df	MS	F	p
Time	3	5744.010	0.48	>.05
S/G	124	12088.747		

Table C7.

Analysis of Variance for NASA-TLX Weighted ratings: Performance

Source	df	MS	F	p
Time	3	1583.594	0.25	>.05
S/G	124	6370.149		

Table C8.

Analysis of Variance for NASA-TLX Weighted ratings: Effort

Source	df	MS	F	p
Time	3	9148.177	0.84	>.05
S/G	124	10880.935		

Table C9.

Analysis of Variance for NASA-TLX Weighted ratings: Frustration

Source	df	MS	F	p
Time	3	71652.279	3.92	<.05
S/G	124	18298.696		

Table C10.

Trend Analysis for Weighted Frustration Subscale

Source	df	MS	F
Linear	1	206460.977	11.42*
Departure from linearity	2	4247.930	0.23
S/G	124	18298.696	

Table C11.

t-tests for pre-vigil standard scores for each scale of the DSSQ

Scale	Mean	t	p
Energetic Arousal	-0.03	-0.396	>.05
Motivation	0.06	0.63	>.05
Concentration	0.08	0.96	>.05
Tense Arousal	0.08	0.96	>.05
Hedonic Tone	-0.11	-1.43	>.05
Control & Confidence	0.78	10.22	<.01
Self-Focused Attention	0.27	3.09	<.05
Self-Esteem	-0.06	-0.78	>.05
Task-Related Cognitive Interference	0.03	0.37	>.05
Task-Irrelevant Cognitive Interference	0.15	1.76	>.05

Note. In each case, df = 127
p values are those obtained after use of the Bonferroni correction.

Table C12.

t-tests for post vs. pre standard scores for each scale of the DSSQ

Scale	Mean Difference	t	p
Energetic Arousal	-0.68	-8.13	<.01
Motivation	-1.06	-12.01	<.01
Concentration	-0.65	-6.32	<.01
Tense Arousal	0.21	2.46	>.05
Hedonic Tone	-0.70	-8.50	<.01
Control & Confidence	-0.62	-7.01	<.01
Self-Focused Attention	-0.65	-6.87	<.01
Self-Esteem	0.64	9.24	<.01
Task-Related Cognitive Interference	0.15	1.73	>.05
Task-Irrelevant Cognitive Interference	-0.01	-0.10	>.05

Note. In each case, df = 127
Mean difference = Post-vigil score – Pre-vigil score.
p values are those obtained after use of the Bonferroni correction.

Table C13.

Analysis of Variance for Pre-vigil scores of the DSSQ

Source	df	df_{adj}	MS	F	p
Between Subjects	127	---			
Modality (A)	1	---	0.005	0.01	>.05
Time (B)	3	---	2.130	2.16	>.05
AB	3	---	0.563	0.57	>.05
S/G	120	---	0.984		
Within Subjects	1152				
Subscales (C)	9	5	8.210	9.47	<.001
AC	9	5	1.088	1.25	>.05
BC	27	17	1.236	1.42	>.05
ABC	27	17	0.939	1.08	>.05
C x S/G	1080	691	0.867		

Note. df_{adj} = degrees of freedom obtained when Box's ε is used to correct for violations of sphericity. Box's ε = 0.64

Table C14.

Analysis of Variance for Post-vigil scores of the DSSQ

Source	df	df_{adj}	MS	F	p
Between Subjects	127	---			
Modality (A)	1	---	1.407	1.38	>.05
Time (B)	3	---	0.371	0.36	>.05
AB	3	---	1.455	1.43	>.05
S/G	120	---	1.018		
Within Subjects	1152				
Subscales (C)	9	5	38.298	42.46	<.001
AC	9	5	1.593	1.77	>.05
BC	27	15	2.383	2.64	<.001
ABC	27	15	1.902	2.11	<.001
C x S/G	1080	604	0.902		

Note. df_{adj} = degrees of freedom obtained when Box's ε is used to correct for violations of sphericity. Box's ε = 0.56

Table C15.

Analysis of Variance for Post-vigil DSSQ Scores: Energetic Arousal

Source	df	MS	F	p
Modality (A)	1	0.324	0.39	>.05
Time (B)	3	0.396	0.48	>.05
A x B	3	0.253	0.31	>.05
S/G	120	0.824		

Table C16.

Analysis of Variance for Post-vigil DSSQ Scores: Motivation

Source	df	MS	F	p
Modality (A)	1	8.975	5.53	<.05
Time (B)	3	1.692	1.04	>.05
A x B	3	2.856	1.76	>.05
S/G	120	1.622		

Table C17.

Analysis of Variance for Post-vigil DSSQ Scores: Concentration

Source	df	MS	F	p
Modality (A)	1	0.044	0.04	>.05
Time (B)	3	2.723	2.19	>.05
A x B	3	3.169	2.55	>.05
S/G	120	1.242		

Table C18.

Analysis of Variance for Post-vigil DSSQ Scores: Tense Arousal

Source	df	MS	F	p
Modality (A)	1	1.885	2.43	>.05
Time (B)	3	4.525	5.83	<.001
A x B	3	2.101	2.71	<.05
S/G	120	0.776		

Table C19.

Analysis of Variance for Post-vigil DSSQ Scores: Hedonic Tone

Source	df	MS	F	p
Modality (A)	1	3.193	4.42	<.05
Time (B)	3	1.697	2.35	>.05
A x B	3	0.781	1.08	>.05
S/G	120	0.722		

Table C20.

Analysis of Variance for Post-vigil DSSQ Scores: Confidence & Control

Source	df	MS	F	p
Modality (A)	1	0.262	0.25	>.05
Time (B)	3	2.903	2.77	<.05
A x B	3	1.494	1.42	>.05
S/G	120	1.048		

Table C21.

Analysis of Variance for Post-vigil DSSQ Scores: Self-Focused Attention

Source	df	MS	F	p
Modality (A)	1	0.026	0.03	>.05
Time (B)	3	0.720	0.82	>.05
A x B	3	0.853	0.97	>.05
S/G	120	0.879		

Table C22.

Analysis of Variance for Post-vigil DSSQ Scores: Self-Esteem

Source	df	MS	F	p
Modality (A)	1	0.005	0.01	>.05
Time (B)	3	0.634	1.28	>.05
A x B	3	0.429	0.87	>.05
S/G	120	0.494		

Table C23.

Analysis of Variance for Post-vigil DSSQ Scores:
Task-Related Cognitive Interference

Source	df	MS	F	p
Modality (A)	1	1.003	1.28	>.05
Time (B)	3	2.817	3.61	<.05
A x B	3	4.094	5.24	<.01
S/G	120	0.781		

Table C24.

Analysis of Variance for Post-vigil DSSQ Scores:
Task-Irrelevant Cognitive Interference

Source	df	MS	F	p
Modality (A)	1	0.028	0.04	>.05
Time (B)	3	3.716	4.99	<.01
A x B	3	2.565	3.45	<.05
S/G	120	0.744		