The Effect of Task and Target Characteristics on the Vigilance Decrement

A dissertation submitted in partial fulfilment of the requirements for the degree of

Masters of Science in Applied Psychology

at the

University of Canterbury

by

Hugh William Stevenson

2010

Research Supervisors:

Dr. William (Deak) Helton

Paul Russell

Table of Contents

List of Figures

Acknowledgements

Thanks to my supervisors Deak Helton and Paul Russell.

1. Abstract

Search asymmetry was used to test two theories of sustained attention lapses currently debated in the literature: the boredom-mindlessness theory and the resource depletion-mental fatigue theory. Participants performed feature present and a feature absent target detection tasks using either a sustained attention to response task (high Go low No-Go) or a traditionally formatted task (high No-Go low Go) response format. In addition to performance, functional near infrared spectroscopy was employed to measure lateral cerebral oxygenation levels and self-reports of tense arousal, energetic arousal, task related and unrelated thoughts occurring during the tasks were utilised. Detections were lower and reaction times longer in the feature absent search than the feature present search regardless of response format. Detections were lower, but reaction times shorter in the sustained attention to response task than the traditionally formatted task regardless of feature search. Greater right than left frontal hemisphere activation occurred in the sustained attention to response task than the traditionally formatted task. In addition, the sustained attention to response task was more fatiguing based on self-reports than the traditionally formatted task, but there were no differences in Task-Unrelated Thoughts across task conditions. Overall, the results of this study support a resource theory explanation of sustained attention lapses, not a mindlessness-boredom theory explanation. Moreover, the results suggest the sustained attention to response task places high response inhibition, not sustained attention, demands on participants.

2. Introduction

Often in day to day life people are required to observe their environment for extended periods of time and detect rarely occurring critical stimuli, while ignoring commonly occurring irrelevant (neutral) stimuli. These tasks have been defined as vigilance or sustained attention tasks (Davies & Parasuraman, 1982; Helton & Warm, 2008; Mackworth 1948; 1950/1961; Matthews, Davies, Westerman, & Stammers, 2000; See, Howe, Warm, & Dember, 1995; Warm 1984).

The earliest work looking formally at such events was conducted by Mackworth (1948). He setup a clock-face task to stimulate a submarine radar search and required workers to observe it and indicate when the hand jumped more than was typical representing a radar "blip". When this happened they were to indicate their awareness to the event. Mackworth found that over longer periods of time workers performance on the observation task deteriorated, this effect has since been defined as the vigilance decrement. It has been observed in a variety of real world scenarios from; scanning luggage for threats, operating a car, or during medical monitoring. These are all situations where the ability to sustain vigilance to important stimuli is crucial (Ballard, 1996; Berch & Kanter, 1984; Damos & Parker, 1994; Davies & Parasuraman, 1982; Hancock & Hart, 2002; Greene, Bellgrove, Gill, & Robertson, 2009).

Much research has been conducted in the field of vigilance. Researchers have investigated differing techniques that can affect the participant's performance on the task. The specific topic I will focus on in this thesis is the causes behind the vigilance decrement and the validity of a relatively new type of vigilance task, the sustained attention to response task.

2.1 Causes of the Vigilance Decrement

What causes the vigilance decrement has been debated extensively in the literature (Bonnedond, Doignon-Camus, Touzalin-Chretien, & Dufour, 2010; Brache, Scialfa, & Hudson, 2010; Greene et al., 2009; Helton & Warm, 2008; MacLean et al., 2009). The two main current competing theories are the resource depletion-mental fatigue theory and the boredom-mindlessness theory. The resource depletion-mental fatigue theory states that people's decrement in performance is due to the inability of people to sustain high levels of sustained attention for long periods of time due to their finite amount of cognitive resources (Kahneman, 1973). Vigilance tasks in general have been seen to be quite taxing on the mental capacity of individuals. This is due to the requirement to constantly monitor the environment for the appearance of a critical stimulus with little opportunity for rest or for taking a break (Davies & Parasuraman, 1982; Helton & Warm, 2008; Hitchcock et al., 1999; Parasuraman, 1979; Temple et al., 2000; Warm, Parasuraman, & Matthews, 2008). Therefore high mental demand leads eventually to the errors that people make (Helton & Warm 2008).

The competing boredom-mindlessness theory states that individuals become bored during vigilance tasks due to a lack of exogenously (external origin) supported attention during these tasks. They must therefore maintain endogenously (internal origin, i.e. rely upon their own conscious control) controlled attention to the critical stimuli. As vigilance tasks are normally mundane and repetitive tasks, the theory states that as time passes people become more and more bored and therefore stop paying attention to the task. As their attention drifts to more interesting task unrelated thoughts (e.g. daydreaming), they begin to make more mistakes. The main proponents of this theory are Robertson and his colleagues (1997) who through laboratory based experimental testing have shown that individuals' thoughts begin to wander during the performance of vigilance tasks. They have attributed this boredom induced mindlessness as the cause of the vigilance decrement (Green et al., 2009; Johnson et al., 2007; Manly et al., 1999; Robertson et al., 1997) This theory is supported by phenomenological reports that many participants find sustained attention tasks to be subjectively boring (Scerbo, 1998)

2.2 Real world differences due to the differing theories behind the vigilance decrement

The differing impact of the two theories of the vigilance decrement in real world applications is very severe. If the designer of a system subscribes to the boredom-mindlessness theory of the cause of the vigilance decrement than the prescribed method for alleviating the decrement in performance is substantively different from those that are prescribed by the resource depletion-mental fatigue theory of the vigilance decrement.

Under the boredom-mindlessness theory, the decrement is occurring due to an under utilisation of the cognitive resources of the individual. This cognitive under-load causes the individual to grow bored with the task and start to have task-unrelated thoughts. This monotony induced conscious drift results in the decrement in the individual's performance. If this were the case, then the easiest way to remedy the performance decrement would be to place the individual under additional cognitive load. Increasing the difficulty and cognitive resources required would reduce the individual's boredom and, thus provide them with less opportunity to have task-unrelated thoughts. For example, individuals who work at the airport and scan luggage on a conveyor belt for potential threats may begin to become bored - one suitcase looks like the rest. If the individual's performance had been found to deteriorate over time then from a boredom-mindlessness approach this could be remedied by placing the individual under greater cognitive load. This could be achieved by increasing the speed of the conveyor belt or adding additional workload, like degrading the image of the luggage (making the task harder).

From a resource depletion-mental fatigue perspective the decreased performance of the individual is due to an over exertion of finite cognitive resources causing the individuals performance to decrease. To alleviate this performance decrement from a resource depletion- mental fatigue approach, the cognitive demands placed upon the individual should be reduced. This would allow them to replenish their finite cognitive resources and reduce their fatigue thus bringing the performance of the individual up to a higher level. Using the same real world scenario as before, the airport conveyor belt; the most effective way to alleviate the performance decrement of the individual would be to allow them to take rest breaks, reduce the speed of the conveyor belt, or improve their signal image. All of these solutions reduce the cognitive stress placed upon the individual and allow their finite cognitive resources to replenish allowing their scanning performance to improve.

This real world scenario exhibits clearly the differences in approach to solving the decrement depending on which explanation is accepted as correct. Research into the cause of the decrement is crucial. The solutions provided by the two theories are fundamentally different and prescribe competing remedies to alleviate the decrement. In actuality, if one were to subscribe to the boredom-mindlessness theory and the real explanation is the resource depletion-mental fatigue theory then placing additional load upon the individual would be disastrous. In the real world example given previously this could lead to a potentially lethal scenario in which a threat item was not detected.

2.3 Sustained Attention to Response Task vs. Traditionally Formatted Task

In the laboratory, the majority of tasks designed to test vigilance performance have been computer driven target detection tasks that have a critical stimuli embedded within a continuous display of neutral stimuli for example, the Continuous Performance Task (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). Within the test environment the majority of tasks that have been performed have been either the sustained attention to response tasks or the traditionally formatted task. The traditionally formatted task was the original type of vigilance task that was used by Mackworth and subsequent researchers in vigilance. Individuals were required to respond to rarely occurring critical stimuli via the pressing of an input device and were not required to formulate any type of response to the frequently occurring neutral stimuli; these tasks are Go/No-Go tasks with a high rate of No-Go and a low rate of Go signals. The sustained attention to response task is a more recent development by Robertson and colleagues (Robertson et al., 1997**)**. The sustained attention to response task requires individuals to make responses to frequently occurring neutral stimuli and to withhold responses to rarely occurring critical stimuli; the sustained attention to response task is again a Go/No-Go task this time with a high rate of Go and a low rate of No-Go signals.

Robertson and colleagues (1997; Dockree et al., 2006; Dockree et al., 2004) have taken the position that the sustained attention to response task is more sensitive to lapses in sustained attention and that these lapses are indicative of a wandering mind. In the sustained attention to response task these lapses are quick to occur and are common even within 4 minutes of task participation. Robertson and colleagues (1997) have interpreted these errors as an indicator of failed sustained attention. They have been less focused on the relative performance decrement over time. However, the High Go, Low No-Go nature of the sustained attention to response task appears to makes it susceptible to feed forward motor impulsive errors or tradeoffs between speed and accuracy (Helton, 2009; Helton et al., 2005; Helton, Kern & Walker, 2009; Helton, Weil, Middlemiss, & Sawers, 2010; McVay & Kane, 2009). Therefore the sustained attention to response task, unlike the traditionally formatted task, leaves some ambiguity as to what the cause of the performance errors are, as the individual can be consciously and perceptually aware of the critical stimulus where a response is not required but unable to withhold a response due to a feed forward motor error (Helton et al., 2010). Robertson and colleagues have acknowledged the sustained attention to response tasks susceptibility of failures of response inhibition (O'Connell et al., 2008) but have continued to argue that it is primarily a measure of sustained attention.

The uncertainty regarding the source of sustained attention to response task error has produced problems for those who are seeking a legitimate measure of sustained attention for diagnostic test purposes or those that are attempting to understand the underlying causes of attention lapses. The sustained attention to response task is very short and convenient. If it does measure the same construct as traditional measures of sustained attention then it will be useful. For the most part the boredom-mindlessness theory advocates have used the sustained attention to response task to investigate sustained attention but not exclusively (see Pattyn, Neyt, Hendreickx, & Soetens, 2008 for a notable exception). Therefore the boredom-mindlessness theory of sustained attention and the measurement concerns of the sustained attention to response task deserve further inspection as they have been interlocked issues.

In the present experiment, participants were randomly assigned to one of two response conditions: a traditionally formatted response paradigm or a sustained attention to response paradigm. In the traditionally formatted response condition participants made responses to rarely occurring critical stimuli while ignoring frequently occurring neutral stimuli. In the sustained attention to response condition the reverse occurred with participants responding to frequently occurring neutral stimuli and ignoring (not responding to) rarely occurring critical stimuli. If the sustained attention to response task is susceptible to speed-accuracy trade offs and response inhibition errors then we expect a greater number of errors in the sustained attention to response task compared to the traditionally formatted task regardless of the type of visual search task employed. However, we also predict that the response times will be quicker for the sustained attention to response task than the traditionally formatted task.

2.4 Target Absent vs. Target Present

In this experiment I investigated the differences between the traditionally formatted task and the sustained attention to response task with the use of two different search tasks. Participants within both response conditions performed two detection tasks, one in which the target (critical) stimuli were defined by the search for the absence of a critical feature of the display paradigm (feature-absent condition) and the other where the critical stimuli were defined by the presence of a specific feature (feature-present condition). The tasks themselves were perceptually identical across the two response conditions with only the mode of responding differing.

Detections of critical stimuli are quicker when searching for the presence of a distinguishing feature than when searching for the absence of such a feature (Quinian 2003; Scerbo, Greenwald, & Sawin, 1993; Treisman & Gormican, 1988). When participants are searching for the presence of a distinguishing feature the type of search that is employed is a parallel search, one where the participant can view the entire display and process the display quickly and the distinguishing feature is likely to “pop out” from the display. When participants are searching for the absence of a distinguishing feature the type of search that is employed is a serial search. This is a more cognitively taxing search where each of the items within the display are searched individually for the absence of the distinguishing feature, taking more time and cognitive effort. This search asymmetry has been accounted for within a feature integration model (Treisman & Gelade, 1980; Treisman & Gormican, 1988). An example of the stimuli utilised in this experiment can be seen in Figure 1.

From the boredom mindlessness perspective, the feature present search task should induce more lapses in sustained attention. This is due to the feature present search task being easier and less cognitively exhausting, as it is a parallel (pop-out) search task, as

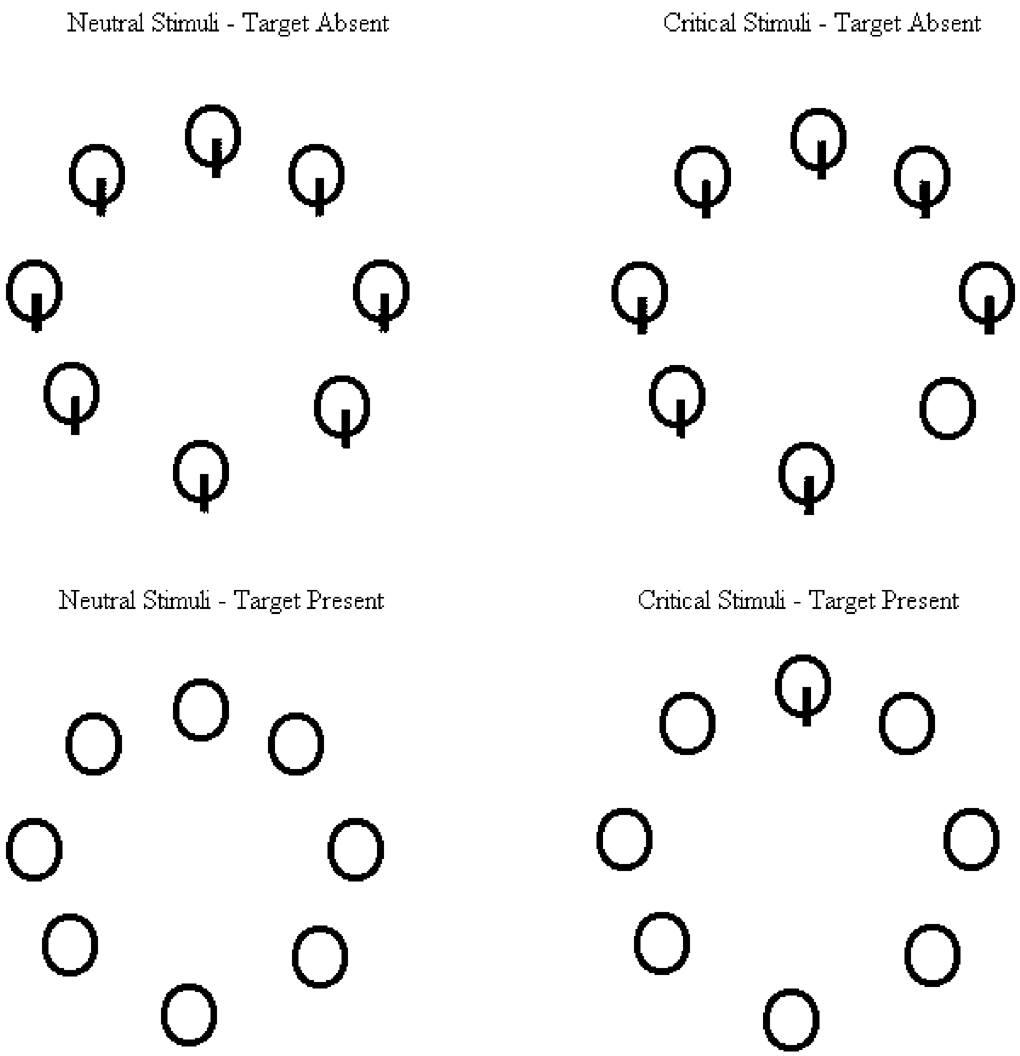

Figure 1. Target feature absent and target feature present stimuli

opposed to the more demanding serial feature absent search task. This in turn will lead to more boredom for the participants and greater mind wandering during the feature present task (Forester & Lavie; 2009; Smallwood, Davies, Heim, Finnigan, Sudberry and

O'Connor, 2004). Furthermore, if Robertson and colleagues are correct the negative performance effect should be even greater in the sustained attention to response condition due to the sustained attention to response task format being more highly susceptible to lapses in sustained attention.

Alternatively, if the resource theory approach to sustained attention is correct, the opposite should occur. Due to the feature absent search being a serial search it should be more demanding and thus more prone to lapses. As it is more cognitively taxing we perceive that there will be higher inducements of fatigue within the participants which will in turn lead to a greater frequency and number of missed detections within the feature absent task regardless of which response condition is used. Moreover, because feature absent search is more cognitively demanding reaction times will be slower for the feature absent search than the feature present search, regardless of the response format.

2.5 Subjective Measures

In addition to the tasks, I employed four scales of the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999,2002) a measure of self-reported subjective state used previously in investigations of vigilance (Grier et al., 2003; Helton et al., 2000, 2004, 2010; Smallwood et al, 2004; Szalma et al., 2004, 2006; Temple, 2000). The scales employed were energetic arousal, tense arousal, task-related thoughts, and task-unrelated thoughts. The DSSQ is given prior to and immediately after the experimental tasks, this allows for a comparison between pre- and post-task states enabling for a detection in state changes. The scales used are derived from different fields of study; the task-related thoughts and task-unrelated thoughts are directly derived from Sarason et al.'s (1986) Task-Related and Task-Irrelevant Cognitive Interference scales.

There are alternatives to global self-report measures, such as using prompts or probes to gather information about the participants' thoughts during the task. One such method is the thought probe method. The thought probe method requires the experimenter to directly ask the participant what they are thinking about at certain points throughout the experiment. While this has the distinct advantage of being more precise when determining occurrence of task-unrelated thoughts throughout the experiment (Smallwood & Schooler, 2006) the probing itself would be distracting for the participants. As this is a high event rate task, the probing itself may even be responsible for failed detections and changes in the participants' moods (see Giambra, 1995). Post-task reports of task-unrelated thoughts have been shown to correlate with random probe reports (r=.5 - .6; Smallwood, Baracaia, Lowe, & Obonsawin, 2003; Smallwood et al., 2004) making them an appropriate alternative indicator of thoughts occurring during task completion.

For the self reports, if the boredom-mindlessness theorists are correct we would expect an increase in task-unrelated thoughts across all conditions. In addition, we would expect an increase in self reports of task-unrelated thoughts in the sustained attention to response task relative to the traditionally formatted task. Robertson and colleagues (1997) have stated that the sustained attention to response task is more susceptible to boredom induced mindlessness than the traditionally formatted task. Alternatively, if the resource theorists are correct, we would expect little difference between levels of task-unrelated thoughts in the sustained attention to response task and the traditionally formatted task. Furthermore, from a resource theorist perspective, we would anticipate task-unrelated thoughts to decrease relative to base line and instead see an increase in the level of task-related thoughts relative to baseline measures. This would demonstrate that the participants are actively engaged with the task and working cognitively hard (Warm, Parasuraman, & Mathews, 2008). From the resource fatigue theory perspective we would expect an increase in the tense arousal levels and a decrease in the energetic arousal levels indicating the high use of limited amounts of cognitive resources and fatiguing of the participant. Further, the sustained attention to response task should be more fatiguing on self-report measures of energetic arousal as it has the addition of response inhibition and speed accuracy trade-offs giving rise to increased demands on cognitive motor inhibition. Resource theorists have indicated that low levels of energetic arousal are indicative of mental fatigue and the depletion of cognitive resources (Matthews et al., 2000)

2.6 Functional Near Infrared Spectroscopy

Finally, to investigate relative levels of fatigue I utilised a measurement of cerebral blood oxygen saturation using functional near infrared spectroscopy (fNIRS; Toronov et al., 2001). This technique measures cerebral tissue oxygen saturation during the tasks. More technically functional Near Infrared Spectroscopy allows functional imaging of brain activity (or activation) through monitoring levels of blood oxygenation and blood volume in the pre-frontal cortex. It does this by measuring changes in the concentration of oxy- and deoxy-haemoglobin (Hb) as well as the changes in the redox state of cytochrome-c-oxidase (Cyt-Ox) by their different specific spectra in the near-infrared range between 700-1000 nm. A commercially available Nonin Model 7600 Near Infrared Cerebral Oximeter (Plymouth, Minnesota, USA) was used and is displayed in Figure 2.

The Nonin Near Infrared Spectroscopy uses three wavelengths of light in the near-infrared spectrum (700 to 900 nm) to determine properties of biological tissue. NIRS can be used to determine the relative amounts of O_2Hb and HHb in the cerebral tissue because Oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb) have distinct optical absorption characteristics. The relative amounts of O_2Hb and HHb are used to calculate regional oxygen saturation (rSO_2). The relationship between an increase in regional oxygen saturation and an increase in blood-oxygenated-level-dependent signal of functional magnetic resonance imaging tells us that both functional near infrared spectroscopy and functional magnetic

Figure 2. A Nonin Model 7600 Near Infrared Cerebral Oximeter (Plymouth, Minnesota, USA).

resonance imaging are similar measures of cerebral activation (see Ekkekakis, 2009 and Gratton & Fabianai, 2007, for more details regarding fNIRS).

The functional near-infrared spectroscopy sensor is attached to the subject's forehead and can be monitored either connected directly to a computer, or a portable computing device that records the subject's data as he or she engages in specific tasks. Figure 3 shows how the light penetrates the skull.

Figure 3. The functional near infrared spectroscopy sensor attached to the frontal lobe emitting near infrared light

The data is recorded and then analyzed for changes in the blood flow or oxygenation levels of the brain before, during, and after the task. Hypotheses can then be tested about how brain activity is being affected by certain tasks or behaviours.

Previous results with this technique show that tissue oxygenation increases with the information processing demands of the task being performed (Helton et al., 2007; Punwani, Ordige, Cooper, Amess, & Clemence, 1998; Toronov et al., 2001). Unlike functional magnetic resonance imaging and positron emission tomography functional near infrared spectroscopy can be used in more naturalistic settings, is less invasive (thereby less stressful), and is less restrictive, thus enabling increased ecological validity.

Work by Toronov et al. (2001) showed that Near Infrared Spectroscopy readings of dexoygenation of blood in the domain near the sensor significantly correlated with concurrent measures of blood oxygen levels dependent from functional Magnetic resonance imaging changes in deoxyhemoglobin concentration.

The measurements taken with the Near Infrared Spectroscopy will allow us to see the amount of activity that is occurring in the participant’s frontal lobes. The right hemisphere has been found to be particularly associated with vigilance type tasks, as well as response inhibition (Punwani et al, 1998). Therefore, an increase in the rSO_2 levels will tell us that more activity is occurring in the hemisphere and if this is found it will further imply that the individual is using more of a limited cognitive resource.

Previous research has indicated right frontal deactivation during vigilance tasks as performance decreases (see Coull, Frith, Frackowiak, & Grasby, 1996; Coull, Frackowiak, & Firth, 1988; Hitchcook et al., 2003; Schnittger, Johannes, Arnavaz, & Munte, 1997; Shaw et al., 2009).

From the boredom-mindlessness perspective, with the functional near infrared spectroscopy we would expect a greater level of deactivation during the sustained attention to response task relative to the traditionally formatted task. This is due to the continuous pressing during the sustained attention to response task inducing a less vigilant state within the participant. If a less vigilant state does occur then we would expect a greater deactivation in the right hemisphere during the sustained attention to response task relative to the traditionally formatted task indicating greater executive disengagement during the sustained attention to response task. Alternatively if the sustained attention to response tasks adds the additional burden of response inhibition and is susceptible to a speed-accuracy trade off, then we would expect a greater increase in physiological activity during the sustained attention to response task relative to the traditionally formatted task, despite the fact that the two tasks are perceptually identical. We would expect a greater increase in right hemisphere frontal activity in the sustained attention to response task in comparison to the traditionally formatted task (Aron, Robbins, & Poldrack, 2004; Garavan, Ross, & Stein, 1999; Helton 2010).

2.7 Predictions

2.7.1 Resource depletion-mental fatigue

Looking at the current experiment from a resource depletion-mental fatigue perspective we can make several hypotheses based upon our predictions.

Hypothesis 1: The sustained attention to response task will produce quicker response times and a greater number of errors than the traditionally formatted task.

The greater cognitive load placed on the participants due to the response inhibition problems associated with the sustained attention to response task will cause a greater number of errors and quicker response times relative to the traditionally formatted task.

Hypothesis 2: Reaction times will be slower and errors will be higher for the feature absent search than the feature present search, irrelevant of response format.

The greater cognitive demands placed upon the individuals due to the more challenging serial search requirements of the feature absent search task will produce greater levels of errors and slower response times than the easier parallel "pop out" search task of the feature present search.

Hypothesis 3: There will be a decrease in the levels of task-unrelated thoughts and energetic arousal and higher levels of task-related thoughts relative to baseline measures.

This decrease in energetic arousal will be greater still for the sustained attention to response task.

As the tasks are cognitively challenging and require the conscious attention of the participant completing them, we expect them to have increased levels of task-related thoughts and decreased levels of task-related thoughts. The levels of energetic arousal are expected to decrease showing that the increased level of cognitive effort to complete the task is mentally fatiguing on the participant. Finally, the decrease in energetic arousal should be greater for the sustained attention to response task due to the requirement of response inhibition.

Hypothesis 4: In the sustained attention to response task there will be a greater activation in the right hemisphere than in the left indicative of increased demands of response inhibition.

Due to the sustained attention to response task being susceptible to response inhibition problems, we expect to see this greater increase in right hemisphere activation as the right hemisphere has been shown to be associated with pre-potent motor inhibition.

2.7.2 Boredom-mindlessness

Alternatively, if the boredom-mindlessness theory of lapses in sustained attention is correct we would hypothesis alternative outcomes.

Hypothesis 1: The sustained attention to response task will produce slower responses and a greater number of errors than the traditionally formatted task.

The difference in this hypothesis compared with the view of the mental fatigue-resource depletion theory is that of the speed of errors. If more mindlessness is taking place then the participants will be slower to react

Hypothesis 2: Reaction time will be faster and errors will be lower for the feature absent search than the feature present search irrelevant of response format.

Due to the more demanding nature of the feature absent search task, this will require more attention from the participants and thus will keep them more engaged and provide less opportunity for boredom.

Hypothesis 3: There will be an increase in the level of task-unrelated thoughts and lower levels of task-related thoughts relative to baseline measures.

The boredom-mindlessness theory of sustained attention states that people grow bored with the vigilance tasks and begin to have task-unrelated thoughts. Consequently, we would expect higher levels of these task-unrelated thoughts and lower levels of task-related thought.

Hypothesis 4: In the sustained attention to response task there will be less activation in the right hemisphere than in the left, indicative of boredom and mindlessness.

If the sustained attention to response task is more susceptible to boredom and mindlessness as proponents of the theory suggest, then we should find less activation in the right hemisphere relative to the traditionally formatted task. Participants are less engaged on the task and thus expending less cognitive resources having task unrelated thoughts.

3. Method

3.1 Participants

Forty participants (20 female, 20 male) comprised of students from the University of Canterbury in Christchurch, New Zealand and paid local area volunteers participated in this study. They ranged in age between 18 and 58 years (*M*=24.4 years, *SE* =1.3). All of the participants had normal or corrected-to-normal vision and were right handed. Participants were reimbursed for their time with a $20 Westfield Mall Voucher. Ethics permission was obtained from the University of Canterbury's human subject research committee prior to commencing this research.

3.2 Materials and Procedure

All participants were tested individually in a small laboratory room which was quiet with no external windows. The room was well lit with ambient illumination by overhead lighting and positioned to minimise glare on the video display terminal (.22 cd/m^2). Each participant was given an information sheet and consent form which they signed prior to the experimental session. All time pieces and mobile phones were switched off. Participants were seated approximately 40 cm in front of a 270mm x 340mm computer screen set at approximate eye level.

Subjective state measures were taken through means of the four scales of the Dundee Stress State Questionnaire (Appendix A; Matthews, Joyner, Gilliland, Huggins, & Falconer, 1999; Matthews et al., 2002): Energetic Arousal, Tense Arousal, Task-Related-Thoughts, and Task-Unrelated-Thoughts. The scales were administered three times during the course of the experiment, upon initially arriving (after completing the Consent Sheet) and after the two experimental conditions in a post-task questionnaire.

The participants were randomly assigned to one of two response conditions balancing for sex: a sustained attention to response task (responding to frequently occurring neutral stimuli and withholding from rarely occurring critical stimuli) or a traditionally formatted task format (responding to rarely occurring critical stimuli and withholding from frequently occurring neutral stimuli). They were also within each response condition randomly assigned to two orders, either starting with a feature absent search task or a feature present search task (see Figure 1 for Examples of experimental stimuli). They then performed the other present or absent task. The order of these tasks was counterbalanced across participants balancing for sex.

During the tasks participants inspected the repetitive presentation of a 60mm x 60mm array of circles. In the feature present task, the array of circles for the neutral stimuli were filled with blank circles and the critical stimuli were created by placing a black line through one of the circles within the array. In the feature absent task, the arrays of circles for the neutral stimuli were filled with circles with a black line through them and the critical stimuli were circles with the absence of the black line. The circle array was presented for 1000ms on a white background. The arrays were then followed by a black visual mask which was presented on screen for 500ms. The order of the presentation was random except for the requirement of the critical stimuli to occur p =.11 and the neutral stimuli to occur p =.89. Participants signalled their detection of the critical stimuli by pressing a button on an electronic input device, only responses made within 1000 ms after the onset of the stimuli were recorded. All participants were given a 1.8 min practice period to familiarise themselves with the task. The main task began directly following the practice period where each task lasted 10.8 min. The two tasks, feature present and absent, were separated by a 10 minute break.

After the completion of the consent form and prior to beginning the experimental conditions participants were fitted with the Near Infrared Spectroscopy. The sensors for the machine were fitted to the participants' forehead symmetrically on the left and right using the centre of the forehead for a line of symmetry. Care was taken to ensure no hair was underneath any of the sensors and to avoid sinus cavities. Sensors were held in place with an adjustable strap. Prior to the beginning of each experimental task, participants were acclimated to the near infrared spectroscopy by a 5 minute baseline period. During the baseline period participants were instructed to maintain relaxed wakefulness, current breathing patterns and to avoid unnecessary movements of their heads. Cerebral oxygenation during this period provided a baseline index (Aaslid, 1986). Their heads were not in a fixed position. To reduce anxiety participants were informed that the near infrared spectroscopy was a non-invasive and painless method for measuring cerebral blood oxygenation. The information regarding cerebral blood oxygen levels was extracted from the Near Infrared Spectroscopy machine via Bluetooth at the conclusion of experimental session for analysis.

Upon completion of the experimental tasks and questionnaires the Near Infrared Spectroscopy machine was removed from the participant and they were debriefed about the experiment and the purpose behind it.

4. Results

4.1 Performance

4.1.1Correct Detections

In the traditionally formatted task a correct detection was defined as key presses to the rarely occurring critical stimuli. In the sustained attention to response task a correct detection was defined as the withholding of key presses to the rarely occurring critical stimuli. The percentage of correct detections in all experimental conditions were subjected to a 2 (response format: traditionally formatted task and sustained attention to response task) x 2 (feature search: absent and present) mixed analysis of variance (ANOVA). The analysis revealed that the overall detection rate in the traditionally formatted task (M = 98.4, SE = 0.4) was significantly higher than that in the sustained attention to response task (M = 72.3, SE – 3.9), F(1,38) = 44.15, p<.001, η_p^2 = .54. The analysis also revealed that the overall detection rate in the feature absent task (M = 84.0, SE =3.1) was significantly lower than in the feature present task (M = 86.8, SE = 2.7), F(1,38) = 4.34, p=.04, η_p^2 = .10. There was no significant interaction between the variables, nor even indications of a trend, p >.10.

4.1.2 False Alarms

In the traditionally formatted task false alarms were defined as key presses to the occurrence of commonly occurring neutral stimuli. In the sustained attention to response task false alarms were defined as withholding key presses to the commonly occurring neutral stimuli. In both tasks the overall false alarm rate was exceptionally low, less than 0.5% therefore false alarms will not be analysed any further.

4.1.3 Appropriate Response Times

Mean appropriate response times (ms) were calculated for both the traditionally formatted task and sustained attention to response task. Response times that were greater than 1000ms were not recorded; therefore the response times were trimmed and appropriate for the analysis of variance. The mean response times in all conditions were subject to a 2 (response format: traditionally formatted Task and sustained attention to response task) x 2 (feature search: absent and present) mixed analysis of variance. The analysis revealed that the response times were significantly slower in the traditionally formatted task (M = 510.6 ms, SE = 11.4) than in the sustained attention to response task (M = 382.0 ms, SE= 13.6), $F(1,38) = 52.38$, $p < .001$, $\eta_p^2 = .58$. The analysis also revealed that response times were significantly slower in the feature absent task (M = 494.7 ms, SE = 14.7) than in the feature present task (M = 397.9 ms, SE =13.2), F (1,38) = 175.31, $p<.001$, $\eta_p^2 = .82$. The interaction was insignificant and did not even indicate a trend, p >.10.

4.2 Physiology

Previous studies using Near Infrared Spectroscopy have recommended using a relative measure of regional oxygen saturation (rSO_2; Yoshitani, Kawaguchi, Tatsumi, Kitaguchi, & Furuya, 2002). Therefore, rSO_2scores were based on a change during the task relative to the baseline period prior to the task. A score of 0 would indicate no change in rSO_2 levels during the task relative to baseline measures. A 2 (response format: traditionally formatted task and sustained attention to response task) x 2 (feature search: absent versus present) x 2 (hemisphere: left and right) mixed analysis of variance revealed a significant interaction between response format and hemisphere, $F(1,38) = 5.47$, $p = .03$, $\eta_p^2 = .13$. This interaction is displayed in Figure 4. All other results were statistically insignificant, nor indicative of any trends, *p* >.10. Supplementary t-tests indicated a significant difference between the right and left hemisphere for the sustained attention to response task, t (19) = 2.53, p = .02, d = .37, but not for the traditionally formatted task, t(19) = .58, p =.57.

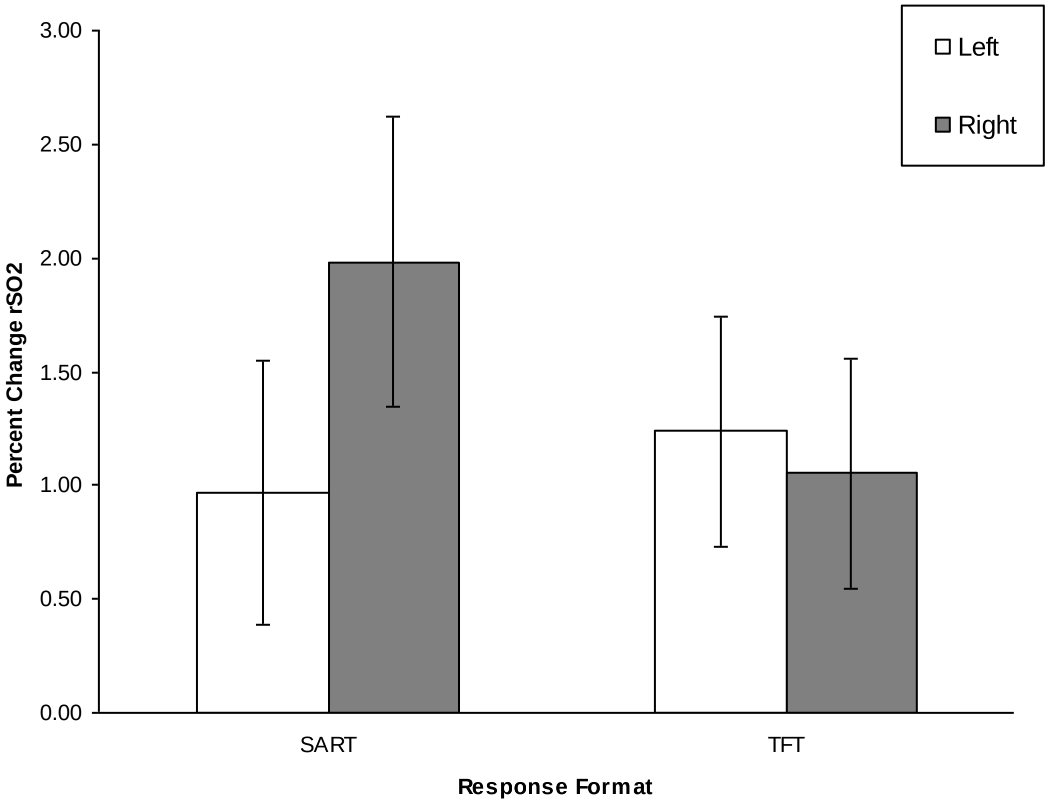

Figure 4. Mean percent rSO2 changes for the right and left hemisphere for the two response conditions: Sustained attention to response task (SART) and Traditionally Formatted Task (TFT) (error bars are standard errors of the mean).

4.3 Subjective Reports

The post-task subjective report scales, Energetic Arousal, Tense Arousal, Task-Related Thoughts and Task-Unrelated Thoughts, were compared to baseline pre-experimental reports in order to asses task-induced changes in subjective state. From self-reports individual change scores were calculated for each participant using the formula, *d*

= (*individual post-score – individual baseline-score),* as has been performed in previous studies (Helton et al., 2000); Helton and Warm, 2008; Szalma et al., 2006). Since all the self-report items were measured on the same response scale (e.g. 1-5), the raw (un-standardised) change scores were used as recommended (Rogosa, 1995). For analysis, the two arousal measures were grouped together and the two thought measures were grouped together.

4.3.1 Energetic and Tense Arousal.

The Energetic Arousal and Tense Arousal change scores were analysed with a 2 (response format: traditionally formatted task and sustained attention to response task) x 2 (feature search: absent versus present) x 2 (measure: Energetic Arousal and Tense Arousal) mixed- ANOVA. This resulted in a significant 3-way interaction, $F(1,38) = 8.82$, $p < .01$, $\eta_p^2 = .19$. This interaction is displayed graphically in figure 5 (error bars are 95% confidence intervals).

The primary pattern is that Energetic Arousal does not differ significantly from baseline (d score = 0) for the traditionally formatted task, but it does differ significantly from baseline for the sustained attention to response task. There was also a significant main effect for measure, $F(1, 38) = 24.25$, $p < .001$, $\eta_p^2 = .39$. The level of Energetic Arousal ($M = -.21$, $SE = .11$) declined during the tasks and the level of Tense Arousal ($M = .48$, $SE = .09$) increased during the tasks relative to pre-task baseline levels. All other results were insignificant and did not indicate any trends, $p > .10$.

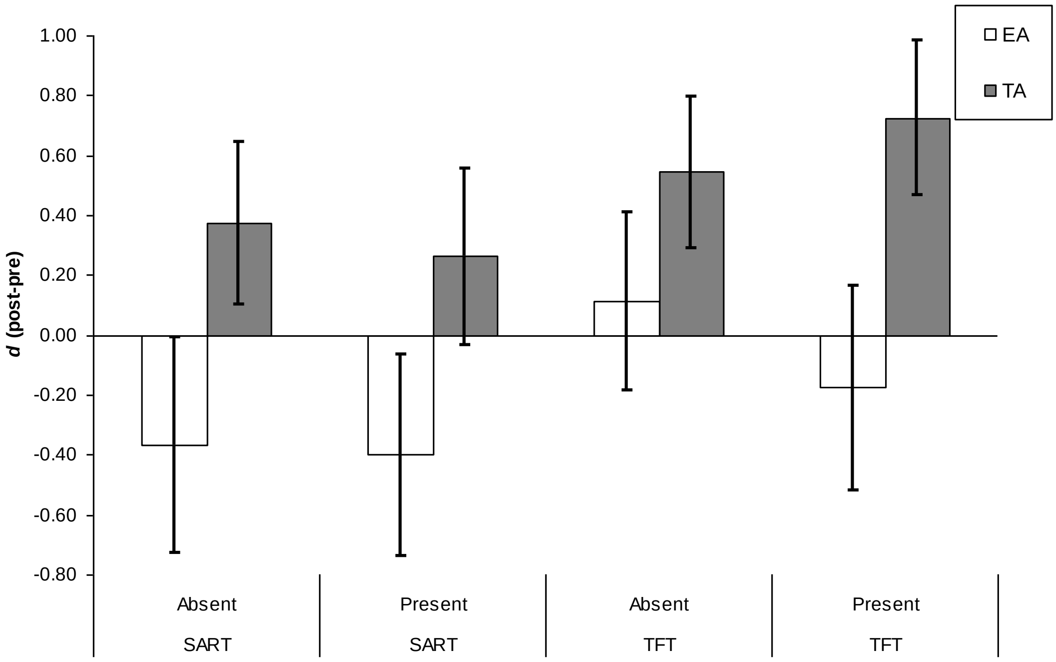

Figure 5. Mean change scores (pre-post) for Energetic Arousal (EA) and Tesnse Arousal (TA) for the four experimental tasks

4.3.2 Task Related and Unrelated Thoughts

The Task Related Thoughts and Task Unrelated Thoughts change scores were analysed with a 2 (response format: traditionally formatted task and sustained attention to response task) x 2 (feature search: absent versus present) x 2 (measure: Task Related Thoughts and Task Unrelated Thoughts) mixed-ANOVA. This analysis resulted in a significant main effect for measure, F (1,38) = 30.94, $p < .001$, $\eta_p^2 = .45$. The level of Task Unrelated Thoughts (M = -.43, SE =.11) declined during the tasks and the level of Task Related Thoughts (M = .43, SE =.09) increased during the tasks relative to pre-task baseline levels. All other results were insignificant, nor indicated any trends, $p > .10$. For comparative purposes the mean change scores for all conditions are displayed graphically in Figure 6 (error bars are 95% confidence intervals).

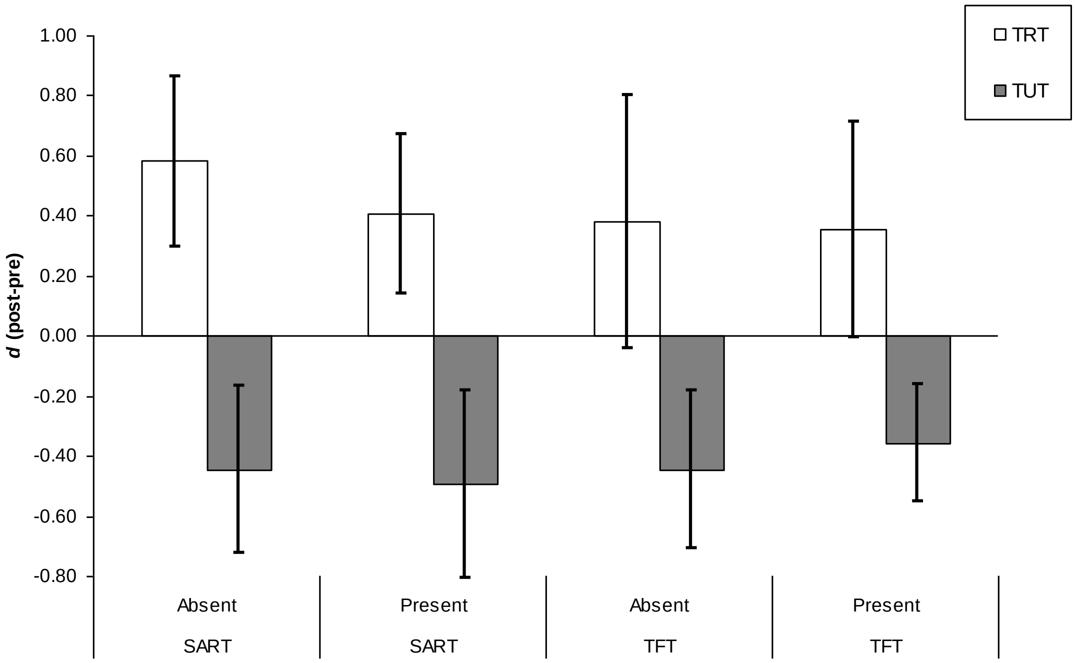

Figure 6. Mean change scores (pre-post) for Task Related Thoughts (TRT) and Task Unrelated Thoughts (TUT) for the four experimental tasks (error bars are 95% Confidence Intervals)

5. Discussion

5.1 General Discussion

The boredom-mindlessness theory of lapses of sustained attention and the interpretation of sustained attention to response task as proposed by Robertson and colleagues (1997; Greene et al., 2009) receives a significant challenge from the results of the current experiment. Decreased performance on the feature absent search task compared to the feature present search task, regardless of the response format, showed that a more cognitively demanding search task impairs vigilance performance. Participants failed to correctly identify critical stimuli more often in the feature absent search task than the feature present search task. This is in line with the predictions of the mental fatigue-resource theory of sustained attention (Helton & Warm, 2008). Previous research has shown that a search for the absence of a feature requires a demanding parallel search of the display and the search for the presence of a feature requires a less demanding serial search (Quinlan 2003; Scerbo, Greenwald & Sawin, 1993; Treisman & Gormican, 1998).

The feature absent search was shown to be more demanding with participants taking longer to respond and having less correct detections relative to the feature present search. This illustrates lapses in sustained attention are primarily the result of mental fatigue and exhaustion of cognitive resources and not boredom (Helton & Warm, 2008; Warm et al., 2008). Also, in the perceptually identical feature search tasks participants missed more critical signals in the sustained attention to response task compared to the traditionally formatted task. This is in line with Helton and colleagues (2005) interpretation of the sustained attention to response task. Additionally, the response times were significantly faster for the sustained attention to response task than the traditionally formatted task. Therefore, the sustained attention to response task can be seen to add more cognitive load on the participant as it has the additional requirement for the participant to inhibit pre-potent responses (e.g. response inhibition) at the same time as focusing sustained attention to external content. These findings support hypothesis 1 regarding appropriate response times across response formats and number of errors and hypothesis 2 regarding differences across feature search from the mental fatigue-resource depletion theory of lapses in sustained attention. It also further distinguishes the possibility of the alternative hypothesis from the boredom-mindlessness theory of lapses in sustained attention.

Pre-post task differential scores from the Dundee Stress State Questionnaire indicated that task-unrelated thoughts (thoughts about things other than the task) decreased during the task relative to pre-task baseline measures and task-related thoughts (thoughts about the task) increased during the task relative to pre-task baseline measures. Additionally there was no difference in the task-unrelated thoughts relative to the response format used by the participants. The sustained attention to response task has been used by Robertson and colleagues (1997) with the view that it is more susceptible to boredom and mindlessness than the traditionally formatted task. This has been shown to be a misconception. Overall, these findings are in line with those of Grier et al (2003) and they indicate a conscious effort to remain focused throughout the task. Further, these findings support hypothesis 3, that there will be a decrease in the levels of task-unrelated thoughts and higher levels of task-related thoughts relative to baseline measures, from the resource depletion-mental fatigue perspective. These findings are contraindicative of the assertions from the boredom-mindlessness perspective.

Self report measures of energetic arousal decreased during the task indicative of mental fatigue, and tense arousal went up, indicative of distress. This is in line with the mental fatigue-resource theory proposed by Helton and colleagues (Helton et al., 2005; Helton & Warm, 2008). The tasks are cognitively demanding and difficult. Further examination of Figure 3, however, indicates the sustained attention to response task was even more fatiguing than the traditionally formatted task. Energetic arousal showed a significant decrease from pre-task baseline (d score of 0) in the sustained attention to response task, whereas there was no significant decrease in the matched traditionally formatted task. These findings also support the assertions of hypothesis 3 regarding the subjective reports of energetic arousal and tense arousal from the mental fatigue-response depletion theory and further bring into question the validity of the boredom-mindlessness theory of lapses in sustained attention.

Greater activation in the right hemisphere (rSO_2) than in the left hemisphere was found in the sustained attention to response task, but not in the perceptually identical traditionally formatted task. The increase in right hemispheric activity during the sustained attention to response task aligns with previous studies which have indicated the importance of the right frontal areas for response inhibition (see Aron et al., 2004; Garavan et al., 1999; Helton, 2010). Considering the tasks were perceptually identical and only different in the type of response format employed, this interpretation of the greater activity is more plausible than one based upon a supposed difference between the types of sustained attention employed in the two conditions. Moreover, if the difference in the lateral response is due to the sustained attention and not response inhibition the results are still contrary to what is expected under the boredom-mindlessness perspective.

If the boredom-mindlessness perspective was correct during the sustained attention to response task, we would expect a marked decrease in sustained attention. This would be shown by greater right hemisphere deactivation comparative to the traditionally formatted response task despite the tasks being perceptually identical, indicating greater executive disengagement. Also, since performance on the sustained attention to response task was worse than on the traditionally formatted task, we would expect a greater decrease in right hemisphere activation for the sustained attention to response task relative to the traditionally formatted task if the decreased performance was indicative of wandering thoughts and not response inhibition (see Coull, Frith, Frackowiak & Grasby, 1996; Coull, Frackowiak, & Firth, 1998; Hitchcook et al., 2003; Schnitter, Johannes, Arnavaz, & Munte, 1997; Shaw et al., 2009).

In summary, the sustained attention to response task is more cognitively demanding than the perceptually identical traditionally formatted task. This illustrates that the sustained attention to response task does not only require sustained attention but also response inhibition. Again the findings support hypothesis 4, the hemispheric activation from the mental fatigue-resource depletion theory of lapses in sustained attention and are contradictory of the hypothesis proposed by the boredom-mindlessness approach.

As demonstrated, the sustained attention to response task is not an improved measure of sustained attention over the traditionally formatted (low-Go) vigilance tasks or a replacement for them, which was the main intention when the sustained attention to response task was designed. Instead, the sustained attention to response task confounds sustained attention with response inhibition and motor control. While the need for abbreviated vigilance tasks to measure sustained attention is clear, better alternatives than the sustained attention to response task exist (for example, Nuecherlein, Parasuraman, & Jiang, 1983; Temple et al., 2000).

Looking at the mindlessness model of sustained attention and not the sustained attention to response task per se, the results of the current experiment are convincing. The results of this experiment are in line with a resource depletion-mental fatigue theory of sustained attention as proposed by Helton and Warm (2008). In reality the boredom-mindlessness theory of sustained attention makes intuitive sense because the vigilance tasks that are performed tend to be repetitive boredom inducing tasks, where participants have often reported wandering thoughts throughout the task. There is however, an appropriate way to integrate this aspect of the boredom-mindlessness theory of lapses in sustained attention with the resource depletion-mental fatigue theory of lapses in sustained attention provided by McVay and Kane (2009). They propose that the occurrence of uncontrollable task-unrelated thoughts throughout the task are caused by an inability of the executive system to inhibit their occurrence and not by boredom and monotony per se. Thus, instead of task-unrelated thoughts being the cause of attention lapses they are in essence a symptom of the same underlying cause, namely depleted cognitive resources.

Active suppression of task unrelated thoughts may be occurring throughout the task, as seen in this experiment, with a decline in the level of task-unrelated thoughts from pre-task levels. Alternatively, task-related thoughts may be used to regulate and maintain task performance. In the present experiment task-related thoughts increased during the task relative to pre-task levels, when the participants were merely anticipating performing the task. Thus task-related thoughts may be an indicator of conscious commitment to task performance. While controlled task-unrelated thoughts (daydreaming) may or may not be engaged in by the participant to relieve boredom and monotony, uncontrolled task-unrelated thoughts or mind wandering may be the results of an inability to keep those thoughts out of the consciousness. Indeed, Martin and colleagues (2006) reported that people often had greater levels of boredom and mind wandering when they are fatigued and depleted.

5.2 Limitations and Future Research

There are several limitations in the current research design that if addressed could improve the quality of the research. With regard to the lack of absence of an increase in task-unrelated thoughts during the task, this null finding may be indicative of the lack of sensitivity of the measure of thoughts used. This method has been used previously in studies and detected significant differences (Smallwood et al., 2004). While not aligning with the prior research the results are in line with what was expected from the mental fatigue-resource depletion perspective. Several other methods reported in the introduction were deemed not relevant for use here as they are distracting and may have caused negative effects. However, future research to confirm the effect would add additional evidence to the findings here and the possible use of alternative methods to provide support could further enhance the external validity of the results.

Recently, Robertson and colleagues have acknowledged the sustained attention to response task is susceptible to response inhibition errors. However, they still try to pass-off the sustained attention to response task as a measure of sustained attention (Greene et al., 2009; Johnson et al., 2007) and have worked on developing a fixed order version of the sustained attention to response task (Dockree et al., 2004; O'Connell et al., 2008) trying to remove the requirement for participants to inhibit motor responses. In the fixed order version of the task participants are aware to the order of events and what number event in the order that they need to withhold a response from (e.g. the numbers 1-8 are displayed individual one after another, continuously and in the same order. The participants are instructed to withhold a response from the number 7). This claim however is problematic; the act of pressing, quickly and often, is liable to result in a feed-forward motor program requiring inhibition (Doyon, Penhune, & Ungerleider, 2003). However, to further test the suitability of the sustained attention to response task as a measure of response inhibition a similar experiment to the one conducted in the research with the fixed order sustained attention to response task may provide additional evidence of its lack of measuring sustained attention and supporting the current findings.

Further research could be directed at investigating the effect of exhaustion on mind wandering. Presumably when people are exhausted they are less likely to be able to keep wandering thoughts out of their consciousness. This lack of control may be labelled subjectively as boredom however, this may not be the case and should be explored further in future studies.

5.3 Practical Applications

Although the sustained attention to response task has been shown here to not be a valid measure of sustained attention, alternative uses can be created based upon the finding that it is a measure of response inhibition. It could provide an excellent paradigm for the investigation of response inhibition and motor control disorders, for example, alien-hand syndrome, as the sustained attention to response task performance results and subjective reports exhibit very similar to disordered motor control (Biran, Giovannetti, Buxbaum, & Chatterjee, 2006; Cheyne, Carriere, & Smilek, 2009).

These results show that in application to the real world the mental fatigue-resource depletion theory of lapses in sustained attention is the correct theory. Super imposing this into the real world example given in the introduction (i.e. the airport conveyor belt) it can be seen that the more appropriate course of action to relieve the individual stresses and create a higher level of performance would be best achieved via the use of tools and aids to decrease the cognitive load placed on the individuals. This could be as simple as the provision of more rest breaks, or specifically in the baggage conveyor belt example, decreasing the speed of the conveyor belt or increasing the quality of the signal image. This affirmation of the mental fatigue-resource depletion theory of lapses in sustained attention also discredits the boredom-mindlessness theory of lapses in sustained attention and the practical applications as prescribed by that theory, for example the placing of additional cognitive load on the individual.

Furthermore, the findings of this research could be used to aid the design of specific jobs and activities where the ability to maintain high levels of sustained alertness and attention are a pre-requisite. To maintain these higher levels of performance job designers could measure how long individuals are able to perform at their peak efficiency and design the work structures and schedules around this to allow for the adequate repletion of cognitive resources to avoid overload.

5.4 Concluding Statement

The hypotheses investigated were all supported from the resource depletion-mental fatigue theory of lapses in sustained attention which conflicted with the hypotheses from the boredom-mindlessness theory of lapses in sustained attention. However, aspects of the boredom-mindlessness model can and should be subsumed in a larger resource perspective. For example, the occurrence of mind-wandering episodes, and the boredom-mindlessness theory has highlighted an area of sustained attention that the resource theorists have often neglected, namely conscious experience. Nevertheless the boredom-mindlessness theorists have largely been misguided, primarily through the use of the sustained attention to response task as a measure of sustained attention (e.g. awareness to external stimuli) when it is actually a better measure of response inhibition (e.g. motor control). Those clinicians and researchers interested primarily in awareness to external stimuli should not use the Sustained Attention to Response Task. There are better measures available (e.g. the abbreviated vigilance task) which provide a better analogue to the longer duration traditional vigilance tasks (see Helton, 2009; Helton & Warm, 2008; Helton et al., 2010; Temple et al., 2000).

6. References

Aaslid, R. (1986). Transcranial Doppler examination techniques. In R. Aaslid (Ed.), *Transcranial Doppler sonography* (pp. 39–59). New York: Springer-Verlag. Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences, 8*, 170-177.

Ballard, J.C., (1996). Computerized assessment of sustained attention: A review of factors affecting vigilance performance. Journal of Clinical and Experimental Neuropsychology, 18, 843-863.

Berch, D.B., & Kanter, D.R. (1984). Individual differences. In J.S. Warm (Ed.), Sustained attention in human performance (pp. 143-178). Chichester, UK: Wiley.

Biran, I., Giovannetti, T., Buxbaum, L., & Chatterjee, A. (2006). The alien hand syndrome: what makes the alien hand alien*? Cognitive Neuropsychology, 23,* 563-582.

Bonnedon, A., Doignon-Camus, N., Touzalin-Chretien, P., & Dufour, A. (2010). Vigilance and intrinsic maintenance of alert state: An ERP study. Behavioural Brain Research, 211, 185-190.

Brache, K., Scialfa, C., & Hudson, C. (2010). Aging and vigilance: who has the inhibition deficit? Experimental Aging Research, 36, 140-152.

Cheyne, J. A., Carriere, J. S. A., & Smilek, D. (2009). Absent minds and absent agents: Attention-lapse induced alienation of agency. Consciousness and Cognition.

Coull, J.T., Frackowiak, R.S.J., & Frith, C.D. (1998). Monitoring for target objects: activation of right frontal and parietal cortices with increasing time on task.Neuropsychologia, 36, 1325-1334.

Coull, J.T., Frith, C.D., Frackowiak, R.S.J., & Grasby, P.M. (1996). A fronto-parietal network for rapid visual information processing: a PET study of sustained attention and working memory. *Neuropsychologia, 34,* 1085-1095.

Damos, D.L., & Parker, E.S (1994). High false alarm rates on a vigilance task may indicate recreational drug use. *Journal of Clinical and Experimental Neuropsychology, 16,* 713-722.

Davies, D.R., & Parasuraman, R. (1982). *The psychology of vigilance.* London: Academic Press.

Dockree, P.M., Bellgrove, M.A., O'Keefe, F.M., Moloney, P., Aimola, L., Cartoon, S., & Robertson, I.H. (2006). Sustained attention in traumatic brain injury (tbi) and healthy controls: enhanced sensitivity with dual-task load. *Experimental Brain Research, 168,* 218-229.

Dockree, P.M., Kelly, S.P., Roche, R.A., Hogan, M.J., Reilly, R.B., & Robertson, I.H. (2004). Behavioural and physiological impairments of sustained attention after traumatic brain injury. *Cognitive Brain Research, 20,* 403-414.

Doyon, J., Penhune, V., & Ungerleider, L. G. (2003). Distinct contribution of the cortico-striatal and cortico-cerebellar systems in motor skill learning. *Neuropsychologia, 41*, 252–262.

Ekkekakis, P. (2009). Illuminating the black box: Investigating prefrontal cortical hemodynamics during exercise with near-infrared spectroscopy. *Journal of Sport and Exercise Psychology*, *31,* 505-553.

Forster, S., & Lavie, N. (2009). Harnessing the wandering mind: the role of perceptual load. *Cognition, 111*, 345-355.

Garavan, H., Ross, T.J., & Stein, E.A. (1999). Right hemispheric dominance of Inhibitory control. *Proceedings of the National Academy of Sciences, U.S.A., 96,* 8301-8306.

Giambra, L.M. (1995) A laboratory based method for investigating influences on switching attention to task unrelated imagery and thought. *Consciousness and Cognition, 4*, 1-21.

Gratton, G., & Fabiani, M. (2007). Optical imaging of brain function. In R. Parasuraman & M. Rizzo (Eds.), *Neuroergonomics: The brain at work (*pp. 65-81). New York: Oxford.

Greene, C.M., Bellgrove, M.A., Gill, M., & Robertson, I.H. (2009). Noradrenergic genotype predicts lapses of sustained attention. *Neuropsychologia, 47,* 591- 594.

Grier, R. A.,Warm, J. S., Dember,W. N., Matthews, G., Galinsky, T. L., Szalma, J. L., & Parasuraman, R. (2003). The vigilance decrement reflects limitations in effortful attention not mindlessness. *Human Factors, 45*, 349–359.

Hancock, P. A., & Hart, S. G. (2002). Defeating terrorism: What can human factors/ergonomics offer? *Ergonomics and Design, 10,* 6–16.

Helton, W.S. (2009) Impulsive responding and the sustained attention to response task. *Journal of Clinical and Experimental Neuropsychology, 31*, 39-47.

Helton, W.S. (2010). The relationship between lateral differences in tympanic membrane temperature and behavioral impulsivity. *Brain & Cognition, 74,* 75- 78.

Helton, W. S., Dember, W. N., Warms, J. S., & Matthews, G. (2000). Optimism, pessimism, and false failure feedback: Effects on vigilance performance. *Current Psychology, 18,* 311-325.

Helton, W.S., Hollander, T.D., Warm, J.S., Matthews, G., Dember, W.N., Wallart, M., Beauchamp, G., Parasuraman, R., & Hancock, P.A. (2005). Signal regularity and the mindlessness model of vigilance. *British Journal of Psychology, 96,* 249-261.

Helton, W.S., Hollander, T.D., Tripp, L.D., Parsons, K., Warm, J.S., Matthews, G., & Dember, W.N. (2007). Cerebral hemodynamics and vigilance performance. *Journal of Clinical and Experimental Neuropsychology, 29,* 545-552.

Helton, W. S., Kern, R. P., & Walker, D. R. (2009). Conscious thought and the sustained attention to response task. *Consciousness and Cognition, 18*, 600-607.

Helton, W.S. & Warm, J.S. (2008). Signal salience and the mindlessness theory of vigilance. *Acta Psychologica, 129,* 18-25.

Helton, W.S., Warm, J.D., Tripp, L.D., Matthews, G., Parasuraman, R., & Hancock, P.A. (2010). Cerebral lateralization of vigilance: A function of task difficulty. *Neuropsychologia, 48,* 1683–1688.

Helton, W. S., Weil, L., Middlemiss, A., & Sawers, A. (2010). Global interference and spatial uncertainty in the Sustained Attention to Response Task (SART). *Consciousness and Cognition, 19*, 77-85.

Hitchcock, E. M., Dember,W. N.,Warm, J. S., Maroney, B.W., & See, J. (1999). Effects of cueing and knowledge of results on workload and boredom in Sustained attention. *Human Factors*, *41*, 365–372.

Hitchcock, E. M.,Warm, J. S., Matthews,G., Dember,W.N., Shear, P. K., Tripp, L.D., Mayleben,D.W., & Parasuraman, R. (2003). Automation cueing modulates cerebral blood flow and vigilance in a simulated air traffic control task. *Theoretical Issues in Ergonomic Science, 4,* 89–112.

Johnson, K.A., Kelly, S.P., Bellgrove, M.A., Barry, E., Cox, M., Gill, M., & Robertson, I.H. (2007). Response variability in attention deficit hyperactivity disorder: Evidence for neuropsychological heterogeneity. *Neuropsychologia ,45,* 630-638.

Kahneman, D. (1973). *Attention and effort.* Englewood, NJ: Prentice Hall.

Mackworth, N.H. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology, 1,* 6-21.

Mackworth, N.H. (1950). Researches on the measurement of human performance. *Medical Research Council Special Report, No. 2680*. London: H.M.S.O. (Reprinted from *Selected papers in the design and use of control systems* pp.174-331, by H.W. Sinaiko Ed., 1961, New York: Dover)

MacLean, K.A., Aichele, S.R., Bridwell, D.A., Mangun, G.R., Wojciulik, E., & Saron, C.D. (2009). Interactions between endogenous and exogenous attention during vigilance. *Attention, Perception, & Psychophysics, 71*, 1042–1058.

Manly, T., Robertson, I.H., Galloway, M., & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia, 37,* 661-670.

Martin, M., Sadlo, G., & Stew, G. (2006). The phenomenon of boredom. *Qualitative Research in Psychology, 3,* 193-211.

Matthews, G., Campbell, S.E., Falconer, S., Joyner, L.A., Huggins, J., Gilliand, K., Grier, R., & Warm, J.S. (2002). Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. *Emotion, 2,* 315-340.

Matthews, G., Davies, D.R., Westerman, S.J., & Stammers, R.B. (2000). *Human performance: Cognition, stress and individual differences.* East Sussex, UK: Psychology Press.

Matthews, G., Joyner, L., Gilliland, K., Huggins, J., & Falconer, S. (1999). Validation of a comprehensive stress state questionnaire: Towards a state big three? In I. Merville, I.J. Deary, F. DeFruyt, and F. Ostendorf (Eds.), *Personality psychology in Europe* (vol. 7) (pp. 335-350). Tilburg: Tilburg University Press.

McVay, J.C., & Kane, M.J., (2009). Conducting the train of thought: working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 196-204.

Nuechterlein, K.H., Parasuraman, R., & Jiang, Q. (1983). Visual sustained attention: Image degradation produces rapid sensitivity decrement over time. *Science, 220,* 327-329.

O'Connell, R.G., Dockree, P.M., Bellgrove, M.A., Turin, A., Ward, S., Foxe, J.J., & Robertson, I.H. (2008). Two types of action error: electrophysiological evidence for separable inhibitory and sustained attention neural mechanisms producing error on Go/No-go tasks. *Journal of Cognitive Neuroscience, 21,* 93-104.

Parasuraman, R. (1979). Memory load and event rate control senstitivity decrements in sustained attention. *Science, 205,* 924-927.

Pattyn, N., Neyt, X., Henderickx, D., & Soetens, E. (2008). Psychophysiological investigation of vigilance decrement: boredom or cognitive fatigue? *Physiology & Behavior, 93,* 369-378.

Punwani, S., Ordidge, R. J., Cooper, C. E., Amess, P., & Clemence, M. (1998). MRI measurements of cerebral deoxyhaemoglobin concentration (dhB)— correlation with near infrared spectroscopy (NIRS). *NMR in Biomedicine, 11,* 281–289.

Quinlan, P.T. (2003). Visual feature integration theory: Past, present, and future. *Psychological Bulletin, 129,* 643-673.

Robertson, I.H., Manly, T., Andrade, J., Baddeley, B.T., & Yiend, J. (1997). ―Oops!: Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35,* 747-758.

Rogosa, D. (1995). Myths and methods: ―Myths about longitudinal research: plus supplemental questions. In J.M. Gottman (ed.) *The analysis of change* (pp. 3-66). Mahwah, NJ: Erlbaum.

Rosvold, H.E., Mirsky, A.F., Sarason, I., Bransome, E.D., & Beck, L.N. (1956). A continuous performance test of brain damage. *Journal of Consulting Psychology, 20,* 343-350.

Sarason, I.G., Sarason, B.R., Keefe, D.E., Hayes, B.E., & Shearine, E. (1986) Cognitive interference: Situational determinants and trait like characteristics. *Journal of Personality and Social Psychology, 51,* 215-226.

Scerbo, M. (1998). What's so boring about vigilance? In R.B. Hoffman, M.F. Sherrick, & J.S. Warm (Eds.), *Viewing psychology as a whole: The integrative science of William N. Dember* (pp. 145-166). Washington, DC: APA.

Scerbo, M. W., Greenwald, C. W., & Sawin, D. A. (1993). The effects of subjectcontrolled pacing and task type on sustained attention and workload. *The Journal of General Psychology, 120*, 293-307.

Schnittger, C., Johannes, S., Arnavaz, A. & Munte, T.F. (1997). Relation of cerebral blood flow velocity and level of vigilance in humans. *NeuroReport, 8,* 1637-1639. See, J.E., Howe, S.R., Warm, J.S., & Dember, W.N. (1995). A meta-analysis of the sensitivity decrement in vigilance. *Psychological Bulletin, 117,* 230-249.

Shaw, T.H., Warm, J.S., Finomore, V., Tripp, L., Matthews, G., Weiler, E., & Parasuraman, R. (2009). Effects of sensory modality on cerebral blood flow velocity during vigilance. *Neuroscience Letters 461,* 207-211.

Smallwood, J., Baracaia, S.F., Lowe, M., & Obonsawin, M.C. (2003). Task-unrelated-thought whilst encoding information. *Consciousness and Cognition*, *12,* 452-484.

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Conner, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition, 13,* 657–690.

Smallwood, J., & Schooler, J.W. (2006). The restless mind. *Psychological Bulletin, 132,* 946-958.

Szalma, J.L., Hancock, P.A., Dember, W.N., & Warm, J.S. (2006). Training for vigilance: The effect of knowledge of results format and dispositional optimism and pessimism on performance and stress. *British Journal of Psychology, 97,* 115-135.

Szalma, J. L.,Warm, J. S., Matthews, G., Dember,W. N.,Wiler, E. M., Meier, A., & Eggemeier, (2004). Effects of sensory modality and task duration on performance, workload, and stress in sustained attention. *Human Factors, 46,* 219–233.

Temple, J.G., Warm, J.S., Dember, W.N., Jones, K.S., LaGrange, C.M., & Matthews, G. (2000) The effects of signal salience and caffeine on performance, workload and stress in an abbreviated vigilance task. *Human Factors, 42,* 183-194.

Toronov, V., Webb, A., Choi, J. H., Wolf, M., Michalos, A., Gratton, E., et al. (2001). Investigation of human brain hemodynamics by simultaneous near-infrared spectroscopy and functional magnetic resonance imaging. *Medical Physics, 28,* 521–527.

Treisman, A.M., & Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Treisman, A.M., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Bulletin, 95,* 15-48.

Warm, J. S. (1984). An introduction to vigilance. In J. S. Warm (Ed.), *Sustained attention in human performance.* (pp. 1–14). Chichester, UK: Wiley.

Warm, J.S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors*, *50*, 433-441.

Yoshitani, K., Kawaguchi, M., Tatsumi, K., Kitaguchi, K., & Furuya, H. (2002). A comparison of the INVOS 4100 and the NIRO 300 near-infrared spectrophotometers. *Anthesia & Analgesia, 94,* 586-590.

7. **Appendix A**

PRE-QUESTIONNAIRE

General Instructions. This questionnaire is concerned with your feelings and thoughts at the moment. Please answer **every** question, even if you find it difficult. Answer, as honestly as you can, what is true of **you**. Your answers will be kept entirely confidential. You should try and work quite quickly. The first answer you think of is usually the best.

Age............. (years)   Sex. M F (Circle one)

Please indicate how well each word describes how you feel **AT THE MOMENT** (circle the answer from 1 to 5).

Not at all = 1 A little bit = 2 Somewhat = 3 Very much = 4 Extremely = 5

1. Energetic	1	2	3	4	5
2. Relaxed	1	2	3	4	5
3. Alert	1	2	3	4	5
4. Nervous	1	2	3	4	5
5. Passive	1	2	3	4	5
6. Tense	1	2	3	4	5
7. Jittery	1	2	3	4	5
8. Sluggish	1	2	3	4	5
9. Composed	1	2	3	4	5
10. Restful	1	2	3	4	5
11. Vigorous	1	2	3	4	5
12. Anxious	1	2	3	4	5
13. Unenterprising	1	2	3	4	5
14. Calm	1	2	3	4	5
15. Active	1	2	3	4	5
16. Tired	1	2	3	4	5

Please indicate roughly how often you had each thought **DURING THE LAST TEN MINUTES.**

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

17. I thought about how I should work more carefully.	1	2	3	4	5
18. I thought about how much time I had left.	1	2	3	4	5
19. I thought about how others have done on this task.	1	2	3	4	5
20. I thought about the difficulty of the problems.	1	2	3	4	5
21. I thought about my level of ability.	1	2	3	4	5
22. I thought about the purpose of the experiment.	1	2	3	4	5
23. I thought about how I would feel if I were told how I performed.	1	2	3	4	5
24. I thought about how often I get confused.	1	2	3	4	5
25. I thought about members of my family.	1	2	3	4	5
26. I thought about something that made me feel guilty.	1	2	3	4	5
27. I thought about personal worries.	1	2	3	4	5
28. I thought about something that made me feel angry.	1	2	3	4	5
29. I thought about something that happened earlier today.	1	2	3	4	5
30. I thought about something that happened in the recent past (last few days, but not today).	1	2	3	4	5
31. I thought about something that happened in the distant past	1	2	3	4	5
32. I thought about something that might happen in the future.	1	2	3	4	5

POST-QUESTIONNAIRE

General Instructions. This questionnaire is concerned with your feelings and thoughts during the task. Please answer **every** question, even if you find it difficult. Answer, as honestly as you can, what is true of **you**. Your answers will be kept entirely confidential. You should try and work quite quickly. The first answer you think of is usually the best.

Please indicate how well each word describes how you felt **DURING THE TASK** (circle the answer from 1 to 5).

Not at all = 1 A little bit = 2 Somewhat = 3 Very much = 4 Extremely = 5

1. Energetic	1	2	3	4	5
2. Relaxed	1	2	3	4	5
3. Alert	1	2	3	4	5
4. Nervous	1	2	3	4	5
5. Passive	1	2	3	4	5
6. Tense	1	2	3	4	5
7. Jittery	1	2	3	4	5
8. Sluggish	1	2	3	4	5
9. Composed	1	2	3	4	5
10. Restful	1	2	3	4	5
11. Vigorous	1	2	3	4	5
12. Anxious	1	2	3	4	5
13. Unenterprising	1	2	3	4	5
14. Calm	1	2	3	4	5
15. Active	1	2	3	4	5
16. Tired	1	2	3	4	5

Please indicate roughly how often you had each thought **DURING THE TASK.**

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

17.	I thought about how I should work more carefully.	1	2	3	4	5
18.	I thought about how much time I had left.	1	2	3	4	5
19.	I thought about how others have done on this task.	1	2	3	4	5
20.	I thought about the difficulty of the problems.	1	2	3	4	5
21.	I thought about my level of ability.	1	2	3	4	5
22.	I thought about the purpose of the experiment.	1	2	3	4	5
23.	I thought about how I would feel if I were told how I performed.	1	2	3	4	5
24.	I thought about how often I get confused.	1	2	3	4	5
25.	I thought about members of my family.	1	2	3	4	5
26.	I thought about something that made me feel guilty.	1	2	3	4	5
27.	I thought about personal worries.	1	2	3	4	5
28.	I thought about something that made me feel angry.	1	2	3	4	5
29.	I thought about something that happened earlier today.	1	2	3	4	5
30.	I thought about something that happened in the recent past (last few days, but not today).	1	2	3	4	5
31.	I thought about something that happened in the distant past	1	2	3	4	5
32.	I thought about something that might happen in the future.	1	2	3	4	5

Appendix B

University of Canterbury

Department of Psychology

INFORMATION

You are invited to participate as a subject in the research project VIGILANCE.

The aims of this project are:

1. Investigate whether exposure to workload has any impact on human performance.

2. Determine if psychophysiological indices, such as near infrared spectroscopy, are predictive of any changes in human performance.

3. Determine whether there are relationships between self-reported state measures (questionnaires), psychophysiological indices, and performance metrics using a variety of statistical and machine learning techniques.

Your involvement in this project will be to participate in a simulated target detection task. Prior to doing the task you will be asked to fill out a questionnaire and will be fitted for some physiological recording devices. These devices will track your blood oxygen level. You will then be provided some training on the target detection task (like a video game). In the task you will be asked to respond (press a button) to a set of selected target items and to withhold a response (ignore) as set of other non-target items. The goal is to select the target items as accurately and quickly as you possibly can. After the completion of the target detection task, we will remove the physiological devices and you will be asked to fill out a post-task questionnaire.

You have the right to withdraw from the project at any time, including withdrawal of any information provided.

In the performance of the tasks and application of the procedures there are minimal risks. There are no known side-effects of the physiological recording equipment used. They are non-invasive, non-painful, and comfortable. The target detection task is similar to playing a video game.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure anonymity and confidentiality, you will be assigned a unique numerical code for the purposes of the study. Any personally identifying information will be kept separate from this code. The data will be kept in a locked cabinet in a locked room in a locked building. The project is being carried out *as* a requirement for course by **X** under the supervision of Dr. Deak Helton, who can be contacted at +64 3 364 2998, ext. 7999. He will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee. Human Ethics Committee Principles and Guidelines 11

University of Canterbury

Dr. Deak Helton Phone: +64 3 364 2998, ext. 7999

Department of Psychology
University of Canterbury
Private Bag 4800
Christchurch
New Zealand

CONSENT FORM

VIGILANCE

I have read and understood the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

I note that the project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee.

NAME (please print): …………………………………………………………….

Signature:

Date:

Human Ethics Committee Principles and Guidelines

Debriefing Sheet

The Effect of Task and Target Characteristics on Vigilance Decrement

The current research focuses on the effects of task and target characteristics on the vigilance decrement. The vigilance decrement occurs when performance on tasks requiring sustained attention decreases over time. Two alternative explanations for the vigilance decrement are being examined; one stating that the decrement is the result of wandering thoughts and the other stating it is the result of mental fatigue, I am predicting that the mental fatigue theory will be more prevalent.

To investigate this two types of sustained attention tasks are being used the Traditionally Formatted Task (TFT) and the Sustained Attention to Response Task (SART). Additionally for each task critical target stimuli will be defined by the presence of a particular feature, or the absence of the feature (feature-present vs. feature-absent conditions). Differing patterns of errors are predicted by the fatigue and wandering thoughts explanations in the conditions formed by the combination of task (TFT vs. SART) and target criteria (feature-present vs. feature absent). Functional Near Infrared Spectroscopy is being used to establish whether the assumed more difficult target characteristic (feature-absence) induces more cerebral activation than the less difficult task (feature-presence) in both the TFT and SART conditions.

Self-report measures before and after task participation of energetic arousal, tense arousal, task related and unrelated thoughts will be used to evaluate the differences between the wandering thoughts and the mental fatigue theories of the vigilance decrement.

This research will provide a clearer picture of the causes of the vigilance decrement which may allow for better design of jobs and roles requiring sustained attention (e.g. Industrial Inspection, monitoring of radar, sonar or other security surveillance)

Appendix C

Table 1.

Tests of Within Subject Effects for Correct Detections

Source		**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Response Format	Sphericity Assumed	.016	1	.016	4.345	.044	.103
	Greenhouse-Geisser	.016	1	.016	4.345	.044	.103
	Huynh-Feldt	.016	1	.016	4.345	.044	.103
	Lower-Bound	.016	1	.016	4.345	.044	.103
Response Format *Feature Search	Sphericity Assumed	.004	1	.004	1.168	.287	.030
	Greenhouse-Geisser	.004	1	.004	1.168	.287	.030
	Huynh-Feldt	.004	1	.004	1.168	.287	.030
	Lower-Bound	.004	1	.004	1.168	.287	.030
Error (Response Format)	Sphericity Assumed	.138	38	.004			
	Greenhouse-Geisser	.138	38	.004			
	Huynh-Feldt	.138	38	.004			
	Lower-Bound	.138	38	.004			

Table 2.

Test of Between Subject Effects for Correct Detections

Source	**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	*58.297*	1	58.297	1897.437	.000	.980
Feature Search	1.356	1	1.356	44.146	.000	.537
Error	1.168	38	.031			

Table 3.

Test of Within Subject Effects for Appropriate Reaction Times

Source		**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig**	**Partial Eta Squared**
Response Format	Sphericity Assumed	187195.770	1	187195.770	175.310	.000	.822
	Greenhouse-Geisser	187195.770	1	187195.770	175.310	.000	.822
	Huynh-Feldt	187195.770	1	187195.770	175.310	.000	.822
	Lower-Bound	187195.770	1	187195.770	175.310	.000	.822
Response Format *Feature Search	Sphericity Assumed	299.532	1	299.532	. 281	.599	.007
	Greenhouse-Geisser	299.532	1	299.532	. 281	.599	.007
	Huynh-Feldt	299.532	1	299.532	. 281	.599	.007
	Lower-Bound	299.532	1	299.532	. 281	.599	.007
Error (Response Format)	Sphericity Assumed	40576.415	38	1067.800			
	Greenhouse-Geisser	40576.415	38	1067.800			
	Huynh-Feldt	40576.415	38	1067.800			
	Lower-Bound	40576.415	38	1067.800			

Table 4.

Test of Between Subject Effects for Appropriate Reaction Times

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	15933941.741	1	15933941.741	2524.265	.000	.985
Feature Search	330645.521	1	330645.521	52.381	.000	.580
Error	239867.711	38	6312.308			

Table 5.

Test of Within Subject Effects for Physiology

Source		Type III Sum of Squares	Df	Mean Square	F	Si g	Partial Eta Squared
Feature Search	Sphericity	6.847E-5	1	6.847E-5	.068	.79	.002
Assumed		6.847E-5	1	6.847E-5	068	6	.002
	Greenhouse-	6.847E-5	1	6.847E-5	068	.79	.002
Geisser		6.847E-5	1	6.847E-5	068	6	.002
	Huynh-Feldt					.79	
	Lower-Bound					6	
						.79	
						6	
Feature Search *Response Format	Sphericity	4.497E-5	1	4.497E	.044	.834	.001
Assumed		4.497E-5	1	-5	. 044	.834	.001
	Greenhouse-	4.497E-5	1	4.497E	. 044	.834	.001
Geisser		4.497E-5	1	-5	. 044	.834	.001
	Huynh-Feldt			4.497E			
	Lower-Bound			-5			
				4.497E			
				-5			
Error (Feature Search)	Sphericity	.039	38	.001			
Assumed		.039	38	.001			

	Greenhouse-	039	38	.001			
Geisser		.039	38	.001			
	Huynh-Feldt						
	Lower-Bound						
Hemisphere	Sphericity	.001	1	.001	2.626	.113	.065
Assumed		.001	1	.001	2.626	.113	.065
	Greenhouse-	.001	1	.001	2.626	.113	.065
Geisser		.001	1	.001	2.626	.113	.065
	Huynh-Feldt						
	Lower-Bound						
Hemisphere* Response Format	Sphericity	.001	1	.001	5.470	.025	.126
Assumed		.001	1	.001	5.470	.025	.126
	Greenhouse-	.001	1	.001	5.470	.025	.126
Geisser		.001	1	.001	5.470	.025	.126
	Huynh-Feldt						
	Lower-Bound						
Error (Hemisphere)	Sphericity	.010	38	.000			
Assumed		.010	38	.000			
	Greenhouse-	.010	38	.000			
Geisser		.010	38	.000			
	Huynh-Feldt						
	Lower-Bound						
Feature Search*Hemisphere	Sphericity	8.257E-7	1	8.257E-	.003	.958	.000
Assumed		8.257E-7	1	7	.003	.958	.000
	Greenhouse-	8.257E-7	1	8.257E-	.003	.958	.000
Geisser		8.257E-7	1	7	.003	.958	.000
	Huynh-Feldt			8.257E-			
	Lower-			7			
Bound				8.257E-			
				7			
Feature Search *Hemisphere * Response Format							
S	Sphericity	.000	1	.000	.660	.422	.017
Assumed		.000	1	.000	.660	.422	.017
	Greenhouse-	.000	1	.000	.660	.422	.017

Geisser		.000	1	.000	.660	.422	.017
	Huynh-Feldt						
	Lower-						
Bound							
Error(Response Format*Hemisphere)							
	Sphericity	.011	38	.000			
Assumed		.011	38	.000			
	Greenhouse-	.011	38	.000			
Geisser		.011	38	.000			
	Huynh-Feldt						
	Lower-						
Bound							

Table 6.

Test of Between Subjects Effects of Physiology.

Source	**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	*164.219*	1	164.219	72501.097	.000	.999
Feature Search	.000	1	.000	.190	.665	.005
Error	.086	38	.002			

Table 7.

Test of Within Subject Effects for Energetic and Tense Arousal

Source		**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig**	**Partial Eta Squared**
Feature Search	Sphericity	*.156*	1	.156	1.039	.31	.027
Assumed		*.156*	1	.156	1.039	5	.027
	Greenhouse-	*.156*	1	.156	1.039	.31	.027
Geisser		*.156*	1	.156	1.039	5	.027
	Huynh-Feldt					.31	
	Lower-Bound					5	
						.31	
						5	
Feature Search *Response Format	Sphericity	.004	1	.004	.023	.879	.001
Assumed		.004	1	.004	.023	.879	.001
	Greenhouse-	.004	1	.004	.023	.879	.001
Geisser		.004	1	.004	.023	.879	.001
	Huynh-Feldt						
	Lower-Bound						
Error (Feature Search)	Sphericity	5.715	38	.001			
Assumed		5.715	38	.001			
	Greenhouse-	5.715	38	.001			
Geisser		5.715	38	.001			
	Huynh-Feldt						
	Lower-Bound						
Measure	Sphericity	18.735	1	18.735	24.248	.000	.390
Assumed		18.735	1	18.735	24.248	.000	.390
	Greenhouse-	18.735	1	18.735	24.248	.000	.390
Geisser		18.735	1	18.735	24.288	.000	.390
	Huynh-Feldt						
	Lower-Bound						
Measure* Response Format	Sphericity	.014	1	.014	.018	.893	.000
Assumed		.014	1	.014	.018	.893	.000
	Greenhouse-	.014	1	.014	.018	.893	.000
Geisser		.014	1	.014	.018	.893	.000
	Huynh-Feldt						
	Lower-Bound						

Error (Measure)	Sphericity	29.361	38	.773			
Assumed		29.361	38	.773			
	Greenhouse-	29.361	38	.773			
Geisser		29.361	38	.773			
	Huynh-Feldt						
	Lower-Bound						
Feature Search*Measure	Sphericity	.375	1	.375	4.377	.043	.103
Assumed		.375	1	.375	4.377	.043	.103
	Greenhouse-	.375	1	.375	4.377	.043	.103
Geisser		.375	1	.375	4.377	.043	.103
	Huynh-Feldt						
	Lower-						
Bound							
Feature Search *Measure* Response Format							
S	Sphericity	.756	1	.756	8.818	.005	.188
Assumed		.756	1	.756	8.818	.005	.188
	Greenhouse-	.756	1	.756	8.818	.005	.188
Geisser		.756	1	.756	8.818	.005	.188
	Huynh-Feldt						
	Lower-						
Bound							
Error(Feature Search*Measure)							
	Sphericity	3.259	38	.086			
Assumed		3.259	38	.086			
	Greenhouse-	3.259	38	.086			
Geisser		3.259	38	.086			
	Huynh-Feldt						
	Lower-						
Bound							

Table 8.

Tests of Between-Subjects Effects for Energetic and Tense Arousal

Source	**Type III Sum**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta**

	of Squares					Squared
Intercept	*2.889*	1	2.889	3.175	.083	.077
Response	4.472	1	4.472	4.915	.033	.115
Error	34.576	38	.910			

Table 9.

Tests of Within-Subject Effects for Task Related and Unrelated Thoughts

Source		**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Si g**	**Partial Eta Squared**
Feature Search	Sphericity	*.066*	1	.066	.463	.50	.012
Assumed		*.066*	1	.066	.463	1	.012
	Greenhouse-	*.066*	1	.066	.463	.50	.012
Geisser		*.066*	1	.066	.463	1	.012
	Huynh-Feldt					.50	
	Lower-Bound					1	
						.50	
						1	
Feature Search *Response Format	Sphericity	.207	1	.207	1.448	.236	.037
Assumed		.207	1	.207	1.448	.236	.037
	Greenhouse-	.207	1	.207	1.448	.236	.037
Geisser		.207	1	.207	1.448	.236	.037
	Huynh-Feldt						
	Lower-Bound						

Error (Feature Search)	Sphericity	5.423	38	.143			
Assumed		5.423	38	.143			
	Greenhouse-	5.423	38	.143			
Geisser		5.423	38	.143			
	Huynh-Feldt						
	Lower-Bound						
Measure	Sphericity	29.972	1	29.972	30.936	.000	.449
Assumed		29.972	1	29.972	30.936	.000	.449
	Greenhouse-	29.972	1	29.972	30.936	.000	.449
Geisser		29.972	1	29.972	30.936	.000	.449
	Huynh-Feldt						
	Lower-Bound						
Measure* Response Format	Sphericity	.375	1	.375	.387	.537	.010
Assumed		.375	1	.375	.387	.537	.010
	Greenhouse-	.375	1	.375	.387	.537	.010
Geisser		.375	1	.375	.387	.537	.010
	Huynh-Feldt						
	Lower-Bound						
Error (Measure)	Sphericity	36.816	38	.969			
Assumed		36.816	38	.969			
	Greenhouse-	36.816	38	.969			
Geisser		36.816	38	.969			
	Huynh-Feldt						
	Lower-Bound						
Feature Search*Measure	Sphericity	.141	1	.141	1.016	.320	.026
Assumed		.141	1	.141	1.016	.320	.026
	Greenhouse-	.141	1	.141	1.016	.320	.026
Geisser		.141	1	.141	1.016	.320	.026
	Huynh-Feldt						
	Lower-						
Bound							
Feature Search *Measure* Response Format							
S	Sphericity	.000	1	.000	.003	.958	.000
Assumed		.000	1	.000	.003	.958	.000
	Greenhouse-	.000	1	.000	.003	.958	.000

Geisser		.000	1	.000	.003	.958	.000
	Huynh-Feldt						
	Lower-						
Bound							
Error(Feature Search*Measure)							
	Sphericity	5.273	38	.139			
Assumed		5.273	38	.139			
	Greenhouse-	5.273	38	.139			
Geisser		5.273	38	.139			
	Huynh-Feldt						
	Lower-						
Bound							

Table 10.

Tests of Between-Subjects Effects for Task Related and Unrelated Thoughts

Source	**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Intercept	*.000*	1	.000	.001	.981	.000
Response	.032	1	.032	.046	.831	.001
Error	25.913	38	.682			