Use of Vibrotactile Stimulation for Sustaining Attention of UAV Operators

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Abstract

Military organizations, including the Canadian Forces (CF), are using Uninhabited Aerial Vehicles (UAVs) to play an increasing role in providing intelligence, surveillance and reconnaissance (ISR). To help improve ISR capability, one area of research that requires investigation is the development of methods that could help UAV crews sustain "acceptable" performance levels in supervisory control tasks. These tasks take place over prolonged periods resulting in a vigilance decrement which is the inability of an operator to sustain attention. To help sustain the attention of UAV operators, this research attempts to develop countermeasures to combat the vigilance decrement of UAV operators. Typical techniques to counteract the vigilance decrement include the provision of a rest break and direct supervision. These existing methods, however, can be intrusive or costly in a UAV control paradigm. To address this problem, this study was designed to investigate the efficacy of vibrotactile signals for sustaining performance in auditory and visual monitoring tasks. In this first phase, 98 participants were tested individually, half of whom were randomly assigned to perform an auditory monitoring task, and the other half performed a visual monitoring task. Participants were exposed to one of four treatments: no treatment or a control condition, a rest break countermeasure condition, a low-occurrence vibrotactile countermeasure condition or a high-occurrence vibrotactile countermeasure condition. A vigilance decrement was found in all the conditions of the study, but no significant evidence for the effectiveness of vibrotactile countermeasures was found. Performance in the auditory modality was greater than that of the visual modality in all conditions. The vigilance task was perceived as a high-stress and high-workload task, based on the results of the NASA TLX and DSSQ questionnaires. In a subsequent phase, an additional 102 participants will be tested to complete the experimental protocol. A suggestion for future research is to study the effect of higher vibrotactile signal amplitudes.

Executive summary

Use of Vibrotactile Stimulation for Sustaining Attention of UAV Operators

Introduction or background:

- Uninhabited Aerial Vehicles (UAVs) are aircraft systems without an onboard pilot or crew. Instead, UAVs are controlled from a remote location. Military organizations, including the Canadian Forces (CF), are using UAVs to play an increasing role in providing intelligence, surveillance and reconnaissance (ISR). To help improve ISR capability, one area of research that requires investigation is the development of methods that could help UAV crews sustain acceptable performance levels in monitoring tasks over prolonged periods. Many existing effective methods (e.g., rest break, direct supervision, and knowledge of results in the form of performance feedback) may not be feasible or practical for real-world military applications. Consequently, there is a need to investigate new methods to sustain performance for the CF UAV crew.

- Purpose of Study: This study was designed to investigate the efficacy of vibrotactile signals for sustaining performance in auditory and visual monitoring tasks.

- Procedure: In this first phase, 98 participants were tested individually in a quiet room at the University of Waterloo. Half of the participants were randomly assigned to perform an auditory monitoring task, and the other half performed a visual monitoring task. In each of the auditory and visual conditions, participants monitored for changes in signal duration and received one of four possible treatments: no treatment (or a control condition), rest break countermeasure, low–occurrence vibrotactile stimulation, and high-occurrence vibrotactile stimulation. All participants subsequently completed a series of questionnaires looking at self-reported workload levels and self-reported stress levels.

Preliminary Results:

A vigilance decrement was found in all the conditions of the study, but no significant evidence for the hypothesis that vibrotactile countermeasures could be a means to combat the vigilance decrement were found.

The study showed the expected effect that the rest break would help to sustain attention in both the auditory and visual modalities of the vigilance task.

Overall performance in the auditory modality was better than performance in the visual modality in all conditions.

There was no significant evidence that the vibrotactile countermeasure would be superior to the rest break.

There were no statistically significant differences in performance levels between any of the vibrotactile countermeasure conditions in their respective modalities.

The vigilance task was perceived as a high stress and high workload task, based on the preliminary results of the NASA TLX and DSSQ questionnaires. The visual task was found to be more physically demanding, possibly due to eye strain and ergonomic discomfort experienced by participants.

Significance:

The results from the study will lead to a greater understanding of the efficacy of a vibrotactile countermeasure for sustaining performance in auditory and visual monitoring tasks. These results could allow researchers to suggest a novel method to improve UAV crew performance in sustained operations, leading to enhanced CF operational effectiveness.

Future plans:

In a subsequent phase, an additional 102 participants will be tested to complete the experimental protocol.

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1 Introduction

1.1 Background

Uninhabited aerial vehicles (UAVs) are aircraft systems without an onboard pilot or crew. Instead, UAVs are controlled from a remote location. Military organizations, including the Canadian Forces (CF), are using UAVs to play an increasing role in providing intelligence, surveillance and reconnaissance (ISR). To improve ISR capability, the CF has recently prepared a statement of work which describes the requirements of a technical investigation to be performed in support of the Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project. The JUSTAS project entails the acquisition of a medium-altitude, long-endurance (MALE) UAV. In support of the JUSTAS project, Defence Research and Development Canada (DRDC) – Toronto is studying human factors issues in UAV control under an applied research program (13QH).

Due to the highly automated nature of UAVs, the main role of UAV operators is one of supervisory control. This involves monitoring the status of a UAV as it completes its mission. Operators may also need to make critical decisions, such as overriding the automation, in order to cope with changes in environmental conditions, mission objectives, or aircraft subsystems. Such monitoring tasks require the constant attention of UAV operators over long watch periods. However, human ability to sustain one's attention tends to diminish over time, making it difficult for UAV operators to remain constantly vigilant over long durations. Therefore, despite the ability of humans to effectively monitor automation (Parasuraman, Molloy, Mouloua, & Hilburn, 1996), maintaining vigilance in monitoring tasks continues to be an issue (Ruff, 2004; Schmidt, Schrauf, Simon, Fritzsche, Buchner & Kincses, 2009).

The study of vigilance investigates human performance for the detection of critical signals that occur infrequently and at irregular intervals over a prolonged period of time. Practical tasks of this nature include detecting targets in military surveillance devices, airport security inspection of x-rayed luggage, prolonged military watch-guard duties, industrial inspection of products, and monitoring of automated systems such as UAVs and nuclear power plants.

A large body of literature on vigilance (sometimes also referred to as sustained attention) has studied the vigilance decrement, which is the diminishing performance of a human operator in prolonged signal detection tasks where critical signals are scarce. The negative effect of the vigilance decrement is an operator's failure to detect critical signals – an effect which can worsen over time. Given the constrained and repetitive nature of such prolonged signal detection tasks, most observers consider vigilance tasks to be boring and monotonous (Thackray, Bailey, & Touchstone, 1979; Thompson et al., 2006). Boredom is associated with feelings of increased constraint, repetitiveness, unpleasantness, and decreased arousal (Finomore, Matthews, Shaw, & Warm, 2009). Boredom has also been shown to negatively affect morale, performance, and quality of work (Thackray, 1981). In operational settings, hazardous states of awareness such as absorption (i.e., oblivious to all but a few elements in the present environment) and preoccupation (i.e., preoccupation with thoughts related to matters outside the present situation) by an individual can be detrimental (Pope & Bogart, 1992). For example, narratives in the Aviation Safety Reporting System database contain descriptions of civil transport flight crew members becoming "complacent" and succumbing to boredom (Pope & Bogart, 1992).

The vigilance decrement itself can be attributed to a drop in an operator's ability to detect critical targets among non-critical noise (also referred to as "sensitivity"), or a subjective bias (e.g. probability of signal occurrence) which the operator uses to judge whether a critical signal has occurred or not (also referred to as a "criterion shift") (Davies and Parasuraman, 1982; Warm, 1984). However, recent evidence suggests the alternative explanation that the information processing demand of a vigilance task is high and thus the decrement reflects the depletion of information-processing resources over time (Matthews, 2001; Caggiano & Parasuraman, 2004; Helton, Hollander, Warm, Matthews, Dember, Wallaart, Beauchamp, Parasuraman & Hancock, 2005; Johnson & Proctor, 2004).

1.2 Rationale of the Study

The results of vigilance research have practical implications for the CF JUSTAS project. A missed detection of a critical signal in a UAV monitoring task, for example, could lead to failure of a mission, costly repairs, or loss of a UAV. The gravity of missed detections has motivated researchers to investigate countermeasures that could sustain "acceptable" performance levels. Examples of countermeasures include the provision of a rest break (Colquhoun, 1959; Floru, Cail, & Elias, 1985; Pigeau, Angus, O'Neill, & Mack, 1995), direct supervision (Bergum & Lehr, 1963; Fraser, 1953), knowledge of results in the form of performance feedback (McCormack, 1959), use of caffeine (Temple, Warm, Dember, Jones, LaGrange & Matthews, 2000), background auditory stimulation for visual vigilance tasks (Davenport, 1974), and even olfactory stimulation (Warm, Dember & Parasuraman, 1991). However, these countermeasures may not be feasible to implement outside a laboratory setting, or practical in the context of military UAV operation. To help overcome these limitations in CF applications, the current study will investigate the efficacy of vibrotactile signals to sustain attention during auditory and visual UAV monitoring tasks. Specifically, short duration vibrotactile signals will be presented on the waist of the participant at intermittent periods while the participant is carrying out a monitoring task, with the aim of sustaining the participant's attention.

Vibrotactile signals have been used to capture user attention in various applications. Vibrotactile alarm systems have been placed under either a pillow or mattress to alert hearing impaired individuals to fire alarms (Bruck & Thomas, 2009). Rumble strips have been placed along highways to provide vibrotactile warning signals to alert drivers of lane deviations (Gardner, Eugene & Margaret, 2007). Vibrotactile warning signals have been used to notify drivers to potential front-to-rear-end collisions in a driving simulator (Ho, Reed, & Spence, 2007). Although the effects of vibrotactile stimulation on vigilance tasks has not yet been studied, the results of the studies mentioned above suggest that vibrotactile signals have the potential to capture attention when the participant is disengaged (e.g., fatigued or bored) during a monitoring task.

1.3 Objective

The objective of the proposed experiment was to simulate a situation whereby an operator must monitor for target signals using one of two sensory modalities (auditory or visual). Participants would then be exposed to one of four possible conditions: no treatment; a rest break; a low vibrotactile condition and a high vibrotactile condition. The objective of the experiment was to determine whether vibrotactile stimulation can serve as a potential countermeasure to the vigilance decrement by enabling participants to sustain attention and maintain performance on the task. To be an effective countermeasure, the vibrotactile stimulation should result in performance better than the control condition. A rest condition is included in order to assess how effective the vibrotactile countermeasure might be relative to a known and effective countermeasure.

1.4 Pilot Study

A pilot study was performed with 32 participants to evaluate the design of the experiment and familiarize the experimenters at the University of Waterloo with the procedures involved in conducting the study and analyzing the results. The results of the pilot study were summarized in a conference paper submission for the Human Factors and Ergonomics Society by Arrabito (2011). Preliminary results of the pilot study showed evidence that vibrotactile stimulation had some effect on maintaining vigilance (or sustained attention) in both modalities.

1.5 Vigilance Theories and Countermeasures

Human performance in vigilance tasks has been studied extensively since the Second World War, when it was used to study the prolonged effects of military surveillance and watch-keeping. In 1948, the British Royal Air Force commissioned N.H. Mackworth to conduct laboratory studies in regards to human vigilance performance (Mackworth, 1950; Warm, 1984). Since Mackworth's preliminary studies, many investigations on factors that affect vigilance behaviour have been conducted using a myriad of experimental paradigms and performance measures (Parasuraman, 1986; Warm, 1984). Past literature has focused on developing a better understanding of why this decrement in performance occurs, and what countermeasures can be taken to overcome this decrement and sustain performance levels. Although several attempts have been made to model the root causes of poor performance in vigilance tasks, the general consensus of more recent literature appears to favour a psychophysiological explanation.

One of the earlier theoretical studies on vigilance was performed on visual scanning of products on an assembly line (Colquhoun, 1959). In these studies, the vigilance decrement was attributed to perceptual "blocks" in the visual modality. The hypothesis was that the perceptual system effectively and momentarily is "closed" to the critical signal in the task after a certain period of time, hence the term "perceptual block". If a critical signal was presented during a perceptual block, then it would be missed by the operator. With vigilance tasks, the frequency of perceptual blocks increases. A rest break countermeasure was proposed to provide a break in the pattern of stimulation, which was deemed sufficient to prevent the increase of the perceptual blocks. Colquhoun later revised this idea, arguing that the vigilance decrement may be caused by changes in an operator's expectation of the probability of occurrence of critical signals (Colquhoun, 1961).

The expectancy theory of vigilance has argued that performance decrements in vigilance tasks may result from an operator's changing expectation that a critical signal may occur (Colquhoun, 1961). Over time, an operator builds an expectation of the probability that a critical signal will occur, given his or her past experience with the task. In tasks where the operator is exposed to a low frequency of signals, the operator develops a lowered expectation that signals will occur. This lowered expectation may lead to a drop in performance. Similarly, operator performance may improve if their expectation of the probability of a critical signal increases (Colquhoun, 1961). In support of this theory, an improvement in performance on vigilance tasks has been observed when participants were trained to expect a relatively high probability of critical signals (Colquhoun & Baddeley, 1964).

Failure in sustained attention has also been attributed to habituation theory (Mackworth, 1968). This theory suggests that the continuous presentation of critical and non-critical stimuli may cause a habituation effect in the human neurophysiological system. This habituation mechanism leads to a sensitivity decrement in a sustained attention task, accounting for the observed decrease in performance during vigilance tasks. Mackworth (1968) proposed that the varied arousal response of the neural system to the uncertain occurrences of critical signals, coupled with changes in the amplitude of arousal for critical versus non-critical events, led to increased "neural noise" over the duration of the vigilance task.

This noise would cause a decrease in the arousal amplitude of a critical signal, effectively lowering an operator's sensitivity to these signals, which would result in a missed detection. Mackworth (1968) suggested changes to the stimulus regularity or saliency in a vigilance task could counteract this habituation, which would lead to a recovery in performance. In a more recent study by Caggiano and Parasuraman (2004), habituation theory appeared not to be supported during a dual-task vigilance experiment. These authors suggested that an attentional resource model of vigilance could be more appropriate. This model is discussed later in this section.

Another proposal has been dubbed the "mindlessness" theory (Robertson et al., 1997). Mindlessness theory suggests that because vigilance tasks are often boring and uneventful, a failure in sustained attention occurs due to the attentional withdrawal of the participant. This theory rests on the assumption that vigilance tasks are low demand and low workload tasks. However, Grier et al. (2003) have found that although traditional views of vigilance perceived it as a low-demand task which led to work underload, vigilance tasks are indeed often stressful, high-workload tasks. Grier et al.'s findings strongly challenge the assumptions behind the mindlessness theory of the vigilance decrement.

A classic theory of vigilance decrement is arousal theory (Frankmann & Adams, 1962). Arousal theory proposes that as people begin to fatigue and their level of physiological arousal decreases. Decreased physiological arousal can result in lower performance, in accordance with the Yerkes-Dodson law (Yerkes & Dodson, 1908). As suggested by the arousal theory, one should be able to counter the vigilance decrement by methods which increase or maintain physiological arousal during long task sessions. Arousal theory has led to several effective countermeasures to the vigilance decrement such as rest breaks (Floru et al., 1985), the introduction of noise (Helton et al., 2009), the use of caffeine (Temple et al., 2000), randomized background stimulation (Davenport, 1974), and olfactory stimulation (Warm et al., 1991). Despite this success, however, there are arguments against the arousal theory of vigilance. In particular, while increased arousal can improve performance in vigilance tasks, it cannot be assumed that the decrease in performance seen in the vigilance decrement can simply be attributed to decreases in arousal. The evidence that vigilance tasks are highly demanding does not support the assumption that people experience a decrease in physiological arousal during these tasks (Grier et al., 2003; Temple et al., 2000). While arousal theory may provide a useful clue to why certain countermeasures are effective against the vigilance decrement, it cannot be assumed that arousal theory alone provides an appropriate explanation of why vigilance decrement happens in the first place.

The general consensus of recent research seems to favour an attentional resource model of vigilance based on the information processing model. Several studies have attributed the vigilance decrement to the depletion of attentional resources over time, without these resources being adequately replenished (Matthews, 2001; Caggiano & Parasuraman, 2004; Matthews et al., 1990; Gunn et al., 2005). Caggiano and Parasuraman (2004) have proposed that the attentional resource model could explain the varying levels of dual-task performance when different pools of information processing resources were used. In this particular experiment, a spatial vigilance task was paired with either a spatial or non-spatial working memory task in two experimental conditions. A sensitivity decrement was found in the spatial memory task condition, but not in the non-spatial condition. This finding supported the multiple resource theory of human information processing, which states that there are different pools of resources available. According to this theory, people may experience different levels of task performance in dual task situations if the tasks tap into different resource pools. These pools could essentially be drained at different rates. This model also appears to account for the effects of physiological arousal. The arousal theory of vigilance suggests that the drop in vigilance performance could be caused by an associated drop in arousal. Doubt was cast on this theory because vigilance tasks are relatively high workload tasks and there is no evidence that subjects experience a drop in arousal. However, Caggiano and Parasuraman

(2004) suggested that sustained attention tasks could lower the availability of some or all information processing resources (Caggianno & Parasuraman, 2004), leading to the vigilance decrement. Other studies that support this model find that providing attentional cues during a vigilance task decreases the load on attentional resources, effectively serving as a countermeasure to the vigilance decrement (Maclean et al., 2009). In addition, Hitchcock et al. (2003) found that cerebral blood flow in the right hemisphere decreased along with vigilance performance, which agrees with the attentional resource model of vigilance partly due to the right hemisphere being responsible for the allocation of attention.

2 Method

2.1 Ethics Approval

The experimental protocol described in this report received clearance from the Human Research Ethics Committee at Defence Research and Development Canada (DRDC), as well as the Office of Research Ethics, at the University of Waterloo.

2.2 Participants

A total of 98 volunteers (comprising of 57 males and 41 females) were recruited from the University of Waterloo community using a poster from the University of Waterloo. Both military and civilians were eligible to participate. The eligible age for participation was between 17 years, with parental consent, or older but did not exceed 60 years. This age range is the allowable age in the CF (http://www.forces.ca/en/page/howtoapply-106#who). Participants self-reported normal hearing and normal or corrected-to-normal vision. None of the participants had previously participated in vigilance experiments. Participation in the study was on a voluntary basis with remuneration set in accordance with DRDC stress allowances. Participants who did not pass the training were remunerated $5. Participants who completed the full two hour study received $40.40. No participants left the experiment at any point; they either did not pass the training or they completed the full experiment. To be eligible to participate, candidates had to be free from self-reported eye and ear disease.

Participants were randomly assigned to one of eight experimental groups as per DRDC Protocol L-753. The breakdown of participants is discussed in the next section, and shown in Table 3.1

The age and sex of participants for each of the eight experimental conditions is presented in Table 1.

Table 1: Age and sex breakdown

Condition	**Mean of Age (SD)**	**Males**	**Females**
Auditory – Baseline	21.67 (4.87)	7	5
Auditory – Rest	23.40 (6.04)	8	3
Auditory – Low Vibrotactile	21.58 (2.97)	6	6
Auditory – High Vibrotactile	21.31 (3.45)	10	3
Visual – Baseline	21.00 (2.00)	5	7
Visual – Rest	21.07 (1.86)	7	7

Visual – Low Vibrotactile	20.18 (2.36)	7	4
Visual – High Vibrotactile	24.00 (9.04)	7	6

2.3 Apparatus

The experiment was conducted in a dedicated room located in the Advanced Interface Design Laboratory at the University of Waterloo. The room was typical of a "quiet private office" with full walls and a closed door. Ambient sound measurements were taken regularly and were found to be consistent, averaging about 38.90 dBA. The lighting in the room was fluorescent tube lighting, again typical of a normal office. The room had a window which allowed for some natural light. Light levels were measured regularly and were consistent with the exception of variability introduced by the natural light from the window. Participants were seated in front of a Philips 22 inch liquid crystal display (LCD) monitor. They were provided with a computer mouse, keyboard, response pad manufactured by Cedrus (San Pedro, CA). The response box consists of seven buttons aligned in a row, with the middle button used for making responses in this study. A Lenovo Intel Core 2 CPU computer served as the host computer in this study. The auditory stimuli from the host computer were presented to the participant binaurally over an AKG 501 headset (Vienna, Austria). The vibrotactile signals were presented using the Engineering Acoustics Inc tactor belt (Orlando, FL) that contained transducers (Mortimer, Zets, & Cholewiak, 2007). There were 3 sizes of belts: small (61-82 cm), medium (76-97 cm), and large (91-112 cm). Each belt was comprised of eight tactors, equidistantly placed around the belt. Customized software running on the host computer was used to present the stimuli, and collect the participants' responses via the subject response pad. All of this equipment was made available to the University of Waterloo by DRDC for the purpose of the experiment.

2.4 Procedure

Each participant was booked for a two-hour experiment time slot. Each perspective participant was assigned a unique randomized participant ID which corresponded to one of eight experimental conditions arranged as follows:

1. Auditory Monitoring Task – Baseline,
2. Auditory Monitoring Task – Rest Break Countermeasure,
3. Auditory Monitoring Task – Low Vibrotactile Countermeasure,
4. Auditory Monitoring Task – High Vibrotactile Countermeasure,
5. Visual Monitoring Task – Baseline,
6. Visual Monitoring Task – Rest Break Countermeasure,
7. Visual Monitoring Task – Low Vibrotactile Countermeasure, and
8. Visual Monitoring Task – High Vibrotactile Countermeasure

Participants were tested individually. Participants were distributed throughout the day to avoid possible time of day effects.

Prior to beginning the study, participants were given a volunteer consent form (Appendix B) that they were required to read and sign. They were also provided with a participant information package which corresponded to their randomly-assigned experimental condition (See Appendix D and Appendix E). Participants were given the opportunity to have their questions or concerns addressed prior to the study (excluding details of the experiment itself) and participants were required to surrender any wristwatch, pager and/or cell phone to prevent distractions while carrying out the study.

Participants in the auditory modality were first required to undergo a cross-modality matching procedure (see Appendix C) which required them to match the loudness of the auditory signal to that of the standard visual signal. Participants were asked to respond according to their own preferences and they were told that there was no right or wrong answer. Participants in the visual modality did not undergo this step.

Following cross-modality matching, participants were fitted with a comfortably-sized belt capable of presenting vibrotactile stimulation, or "tactor belt". They were then taken through the stimuli familiarization mode of the experiment software until they felt confident that they could distinguish between the target signal and non-target signal. Following familiarization, each participant was asked to complete a training session which resembled a condensed version of the baseline experiment for their assigned modality. The training procedure consisted of 5 critical signals and 195 non-critical signals, essentially half of an experimental vigil. The participants were told to continuously monitor for signals, and respond to critical signals by pressing a red button on the subject response box. All participants were cautioned that accuracy was not to be sacrificed for speed. The participants were required to score no less than 4/5 hits and no more than 20 false alarms out of a total of 200 signals. No performance feedback was provided to the participant. Each participant was given at most two tries to pass the training criteria.

Upon successfully completing the training session, the participants were told that they would complete the main experiment, and were given similar instructions to those of the training session. Regardless of group assignment, the experimenter presented a series of tactile sequences so that participants could be familiarized with the vibrotactile signals from the belt. Again, regardless of condition, the experimenter specified that vibrotactile signals may be presented intermittently throughout the study and that these signals were to be ignored and would be unrelated to their performance in the monitoring task. Each participant was then tasked to complete one of eight experimental conditions. The eight experimental conditions were arranged as a between- subjects design. The between-subject factors are sensory modality (auditory and visual), and type of countermeasure (baseline, rest break, low vibrotactile signals, and high vibrotactile signals). Each participant completed four continuous 10 minute vigils for a total of 40 minutes. For each vigil, the probability of occurrence of the critical signal was 10/400 (2.5%) – a rate reported in previous vigilance studies (Galinsky, Rosa, Warm, & Dember, 1993; Szalma et al., 2004). The dependent variables were the percentage of correct detections of the critical signal (i.e., hits), the false alarm rate (i.e., the percentage of trials on which the participant indicates that he/she has detected the critical signal when in fact the critical signal was not presented), and the response time to detect the critical signal. The order of stimuli and vibrotactile signals were randomized for each participant. Participants were told that response time would be measured, that they would not receive feedback on their performance, and they were not informed that performance would be assessed in 10-minute vigils.

Similar vigil durations have been used in previous studies – Gunn et al. (2005) used three 10.8-minute vigils for a UAV target acquisition vigilance task. Szalma et al. (2004) included 10, 20, 30, and 40 minute vigils in which only the final 10 minute vigils were considered for performance analysis. Helton and

Warm (2008) used a single 12-minute vigil for a visual monitoring task. Although most vigilance studies have focused on signal detection in the visual modality, there have been previous studies which have compared monitoring performance between the auditory and visual modalities (Osborn et al., 1963; Szalma et al., 2004).

Following the experimental session, half of the participants completed a computerized version of the National Aeronautics and Space Administration - Task Load Index (NASA-TLX; Hart & Staveland, 1988), which is a measure of perceived mental workload and aa paper version of the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999), which is a measure of transient states associated with mood, arousal, and fatigue. To avoid possible testing bias, half of the participants for each sensory modality were randomly assigned to complete the NASA-TLX, followed by the DSSQ. The other half were randomly assigned to complete the DSSQ, followed by the NASA-TLX**.** Participants in each of the four tactile conditions were asked to complete a tactile annoyance questionnaire (Appendix F) as well. Participants in the vibrotactile countermeasure conditions completed an additional questionnaire to assess the annoyance level of the vibrotactile signals (Appendix F).

2.4.1 Monitoring Task

The participants in the baseline conditions performed four consecutive vigils with no break or intervention. For participants in the other countermeasure conditions, the rest break and vibrotactile interventions occurred following the third vigil. Participants assigned to the visual and auditory rest break countermeasure groups were given a five-minute rest break between the third and fourth vigils. Specifically, at the 30-minute mark of the 40-minute monitoring task, a message was presented on the computer monitor instructing participants to meet with the experimenter. Participants exited the testing room. During the rest break, participants were not allowed to consume food or drink or smoke. Following the rest break, participants continued to complete the fourth vigil. Participants assigned to the auditory and visual vibrotactile countermeasure groups had 16 distinct vibrotactile patterns (see Figure 1) presented intermittently throughout the fourth vigil. In the low vibrotactile condition, 30% of the trials presented a vibrotactile signal. In the high vibrotactile condition, 70% of the trials presented a vibrotactile signal. The patterns were presented in a random order without replacement until all 16 patterns were presented. Subsequently, the 16 patterns were re-used in a random order without replacement. This process was repeated until the selected number of trials, 30% or 70%, had the presentation of a vibrotactile signal. The vibrotactile signal was presented 600 ms following signal offset. Participants were not required to detect or discriminate the vibrotactile pattern.

2.4.2 Data Logged

The subject code, group, vigil, trial number, signal type (critical/non-critical), time of signal onset from beginning of the vigil, response type (i.e., hit, miss or false alarm) and response time were logged, along with relevant information regarding vibrotactile signals including presence, time of onset in the trial, and tactile sequence number. The sound and light levels of the experiment room were also measured and recorded.

2.5 Stimuli

2.5.1 Auditory

Signals were a short-duration burst of white noise (a hissing sound). The duration of the critical signal was 200 ms, and the duration of the non-critical signal was 247.5 ms. The type of noise and duration was based upon previous work, which showed that the critical signal is salient (Galinsky et al., 1993; Szalma et al., 2004). The intensity of the signals was determined for each participant based on a cross modality matching procedure (Gescheider, 1997), which is described in Appendix C.

2.5.2 Visual

The signals were a horizontal bar measuring 2 mm x 9 mm, displayed on the computer monitor and centred against a grey background. The luminance of the horizontal bar was 17.5 cd/m^2 and that of the grey background was 0.38 cd/m^2. The duration of the critical signal was 125 ms, and the duration of the non-critical signal was 247.5 ms. The type of symbol and duration were based upon previous work, which showed that the critical signal is salient (Galinsky et al., 1993; Szalma et al., 2004).

2.5.3 Vibrotactile

Vibrotactile signals were presented through a belt which contains 8 C-2 tactors and was manufactured by Engineering Acoustics (Orlando, FL). Each signal consisted of four of the eight tactors activated on a low duty cycle (10%) at 250 Hz, a burst pulse duration of approximately 200ms and a vibratory amplitude of approximately 0.5mm (peak to peak). Participants experienced sequences of vibrotactile stimuli as shown in Figure 1.

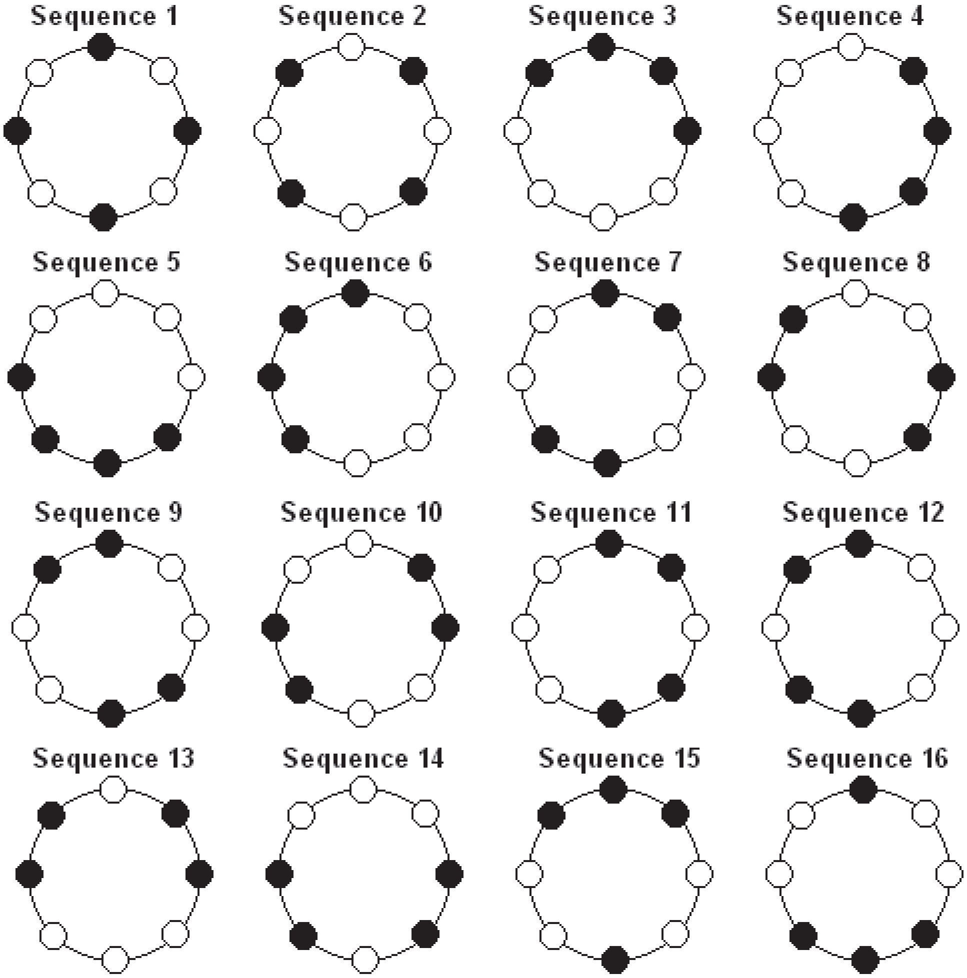

Figure 1: Vibrotactile sequences presented on participant's waist via a belt that contains eight equally spaced tactors. The navel is represented by 12 o'clock position on circle, the spine is represented by 6 o'clock position on circle. Solid shading denotes active tactors. All 4 tactors are presented simultaneously with identical parameters: frequency = 250 Hz; total duration = 200 ms; pulse duration = 50 ms; on-time duration = 5 ms; vibratory amplitude of approximately 0.5 mm (peak to peak).

2.6 Hypotheses

The following hypotheses were made:

1) All eight experimental groups would exhibit a vigilance decrement, defined as a significant drop in performance, within the first 30 minutes of the watch. This would confirm the observations found by Mackworth (1950) for both visual and auditory monitoring tasks.

2) The participant groups completing the visual monitoring task would have a significantly larger decrement compared to corresponding participant groups completing the auditory monitoring task. Szalma et al. (2004) equated auditory and visual vigilance tasks in discrimination

difficulty and found that performance deteriorated with time-on-task, and that the auditory modality was superior to the visual modality.

3) The rest break countermeasure groups would have significantly better monitoring performance compared to corresponding baseline groups in the auditory and visual modalities. Previous studies showed that rest periods have beneficial effects on monitoring performance (Mackworth, 1950; Pigeau et al., 1995).

4) The vibrotactile countermeasure groups would have significantly better monitoring performance compared to the corresponding baseline groups in the auditory and visual modalities. Vibrotactile signals have been shown to capture attention in various applications (e.g., Bruck & Thomas, 2009; Ho et al., 2007; Gardner et al., 2007).

5) The high vibrotactile group would have significantly poorer monitoring performance than the low vibrotactile group in both the visual and auditory modalities. This might be explained by a habituation mechanism (e.g., Koelega, Brinkman, & Bergman, 1986). The term habituation mechanism refers to adaptation, which “may be generally defined as a reduction in sensitivity resulting from a continuous unchanging stimulus” (Cheung, van Erp, & Cholewiak, 2008, p. 2-4).

6) The monitoring performance for the vibrotactile countermeasure groups would not be significantly different from the monitoring performance of the corresponding rest break countermeasure groups in both the visual and auditory modalities. Various countermeasures exist for mitigating the vigilance decrement (Davies & Parasuraman, 1982).

3 Results

3.1 Statistical Analysis

The percentages of correct detections and false alarms, and mean response times were calculated for each participant in all the 10-minute vigils of each experimental condition. At this stage, only preliminary statistical results are provided in order to assess the study at the midway point. Analyses were performed on selected comparisons of interest using a between-subjects analysis of variance (ANOVA). The analysis of the efficacy of each countermeasure was based on the final 10-minute vigil of each experimental group. Analyses across vigils include within subject comparisons of changes between vigils.

3.2 Performance Results

3.2.1 Performance by Modality

Figure 2 shows the percentage of correct detections for each modality averaged over all conditions across the four vigils. A general decline in performance can be observed from vigil one to vigil four for both modalities. The auditory modality showed higher overall performance than the visual modality.

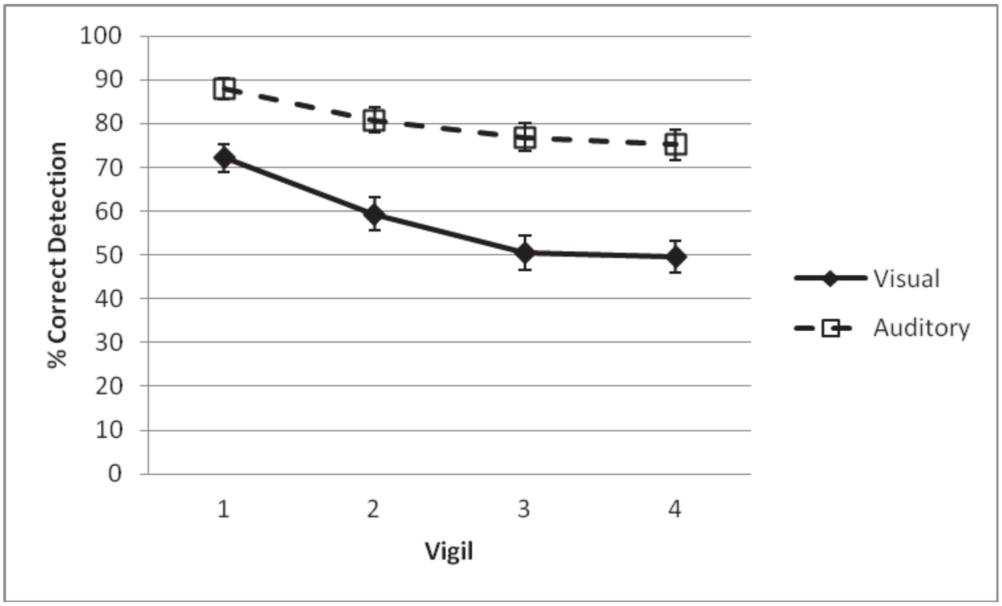

Figure 2: Cross-vigil comparison of hits for baseline condition. The error bars show the standard error of the mean.

3.2.2 Performance Across Vigils

In order to observe the progression of average performance (by percentage of correct detections) over time, cross-vigil comparisons were made across modalities and conditions. Figure 3 and Figure 4 compare the progression of performance by the percentage of correct detections (hits) for experimental condition in the visual and auditory modalities, respectively. The error bars show the standard error of the mean.

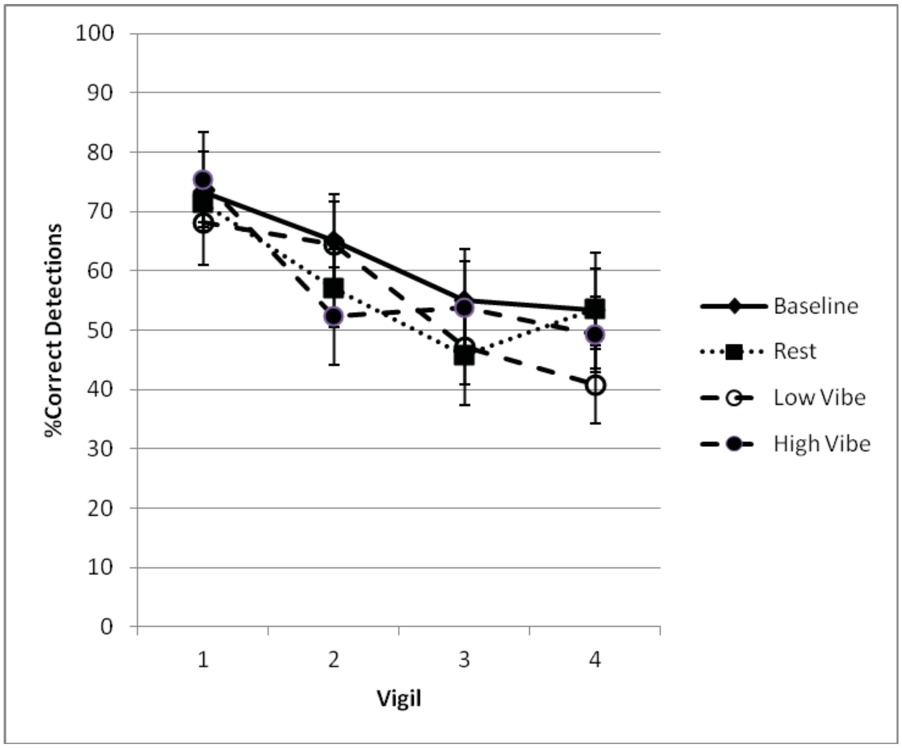

Figure 3: Cross-vigil comparison of correct detection rates in the visual modality

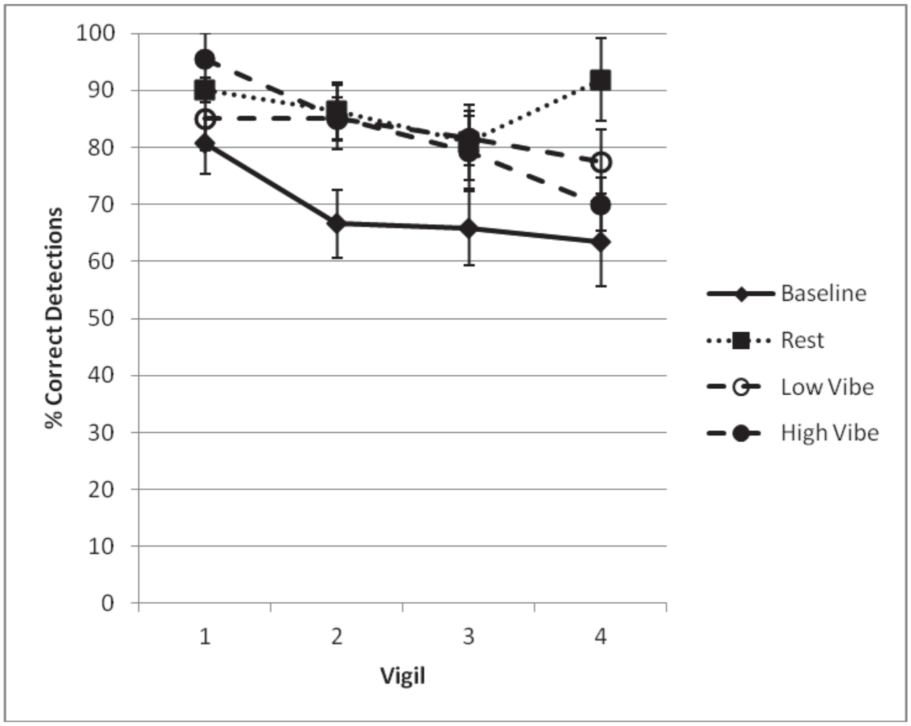

Figure 4: Cross-vigil comparison of correct detection rates in the auditory modality

In the baseline condition, a decline in performance can be observed from one vigil to the next for both modalities. For the rest break condition, a decline in performance was observed from vigil one to vigil three, and a performance improvement across the final vigil, for both modalities. The auditory modality showed higher overall performance than the visual modality. In the low (30%) and high (70%) vibrotactile conditions, a decline in performance can be observed from one vigil to the next for both modalities, but a higher overall number of correct detections occurred in the auditory modality.

Figure 5 and Figure 6 below present cross-vigil comparisons of false alarm rates for all conditions in the visual and auditory modalities, respectively. In general, false alarm rates decreased until the third vigil. False alarm rates continued to decrease in the final vigil in the rest and low vibrotactile conditions.

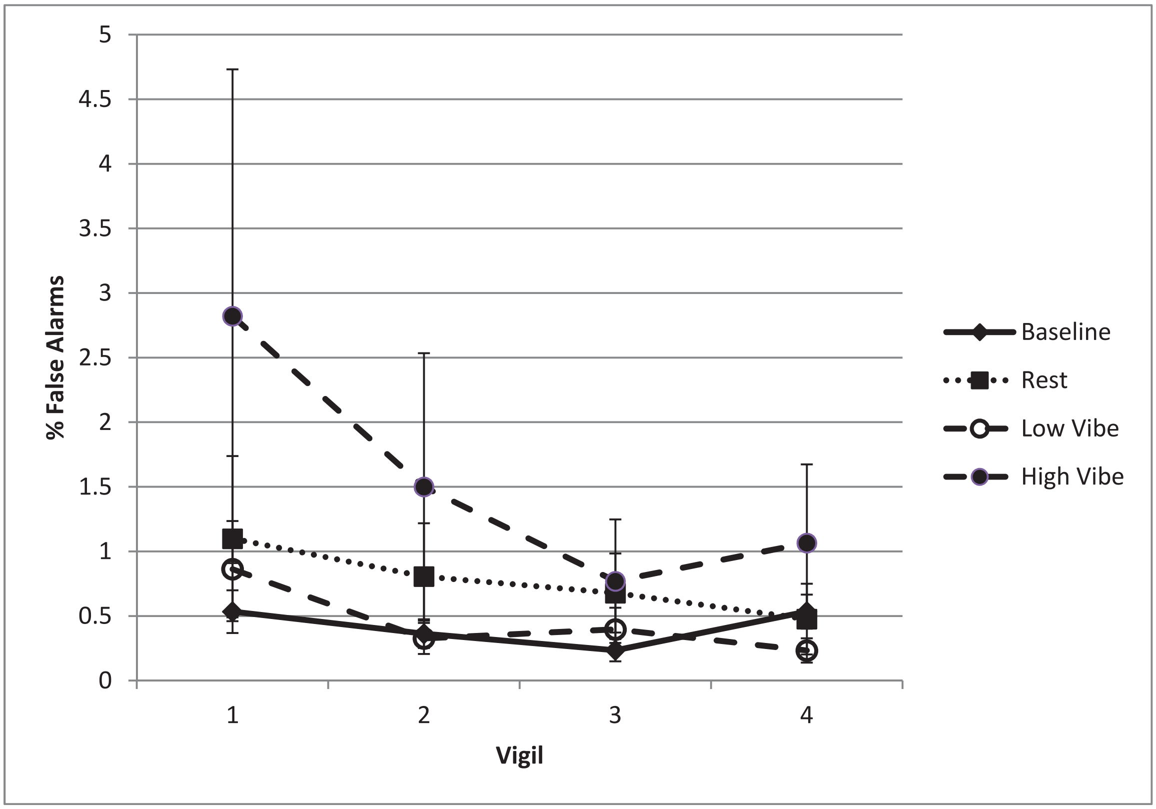

Figure 5: Cross-vigil comparison of false alarm rates in the visual modality

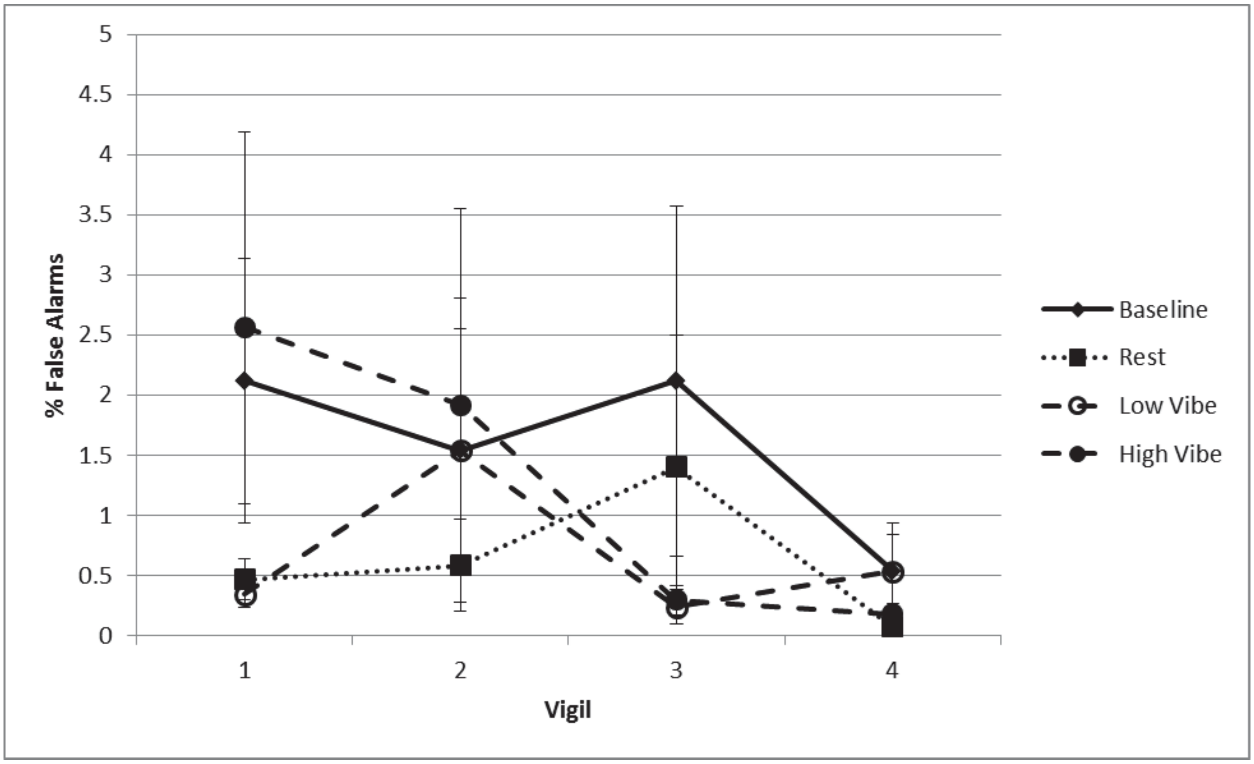

Figure 6: Cross-vigil comparison of false alarm rates in the auditory modality

3.2.3 Performance by Countermeasure Condition

The mean percentages of correct detections (or Hits) of critical signals in the final vigil are presented across conditions and modalities in Figure 7. Accuracy was significantly greater in the auditory modality than in the visual modality, confirmed by a between-subjects ANOVA, based on an arcsine transformation of the hit rates, $F(1, 90)=26.64$, $p<0.0001$.

In the Auditory modality, only the rest break countermeasure condition had significantly more correct detections of the critical signal than the baseline condition $F(3,44) = 4.66$, $p<0.05$. In the Visual modality, there were no significant differences between the countermeasure conditions and the baseline condition ($p>0.05$). The error bars show the standard error of the mean.

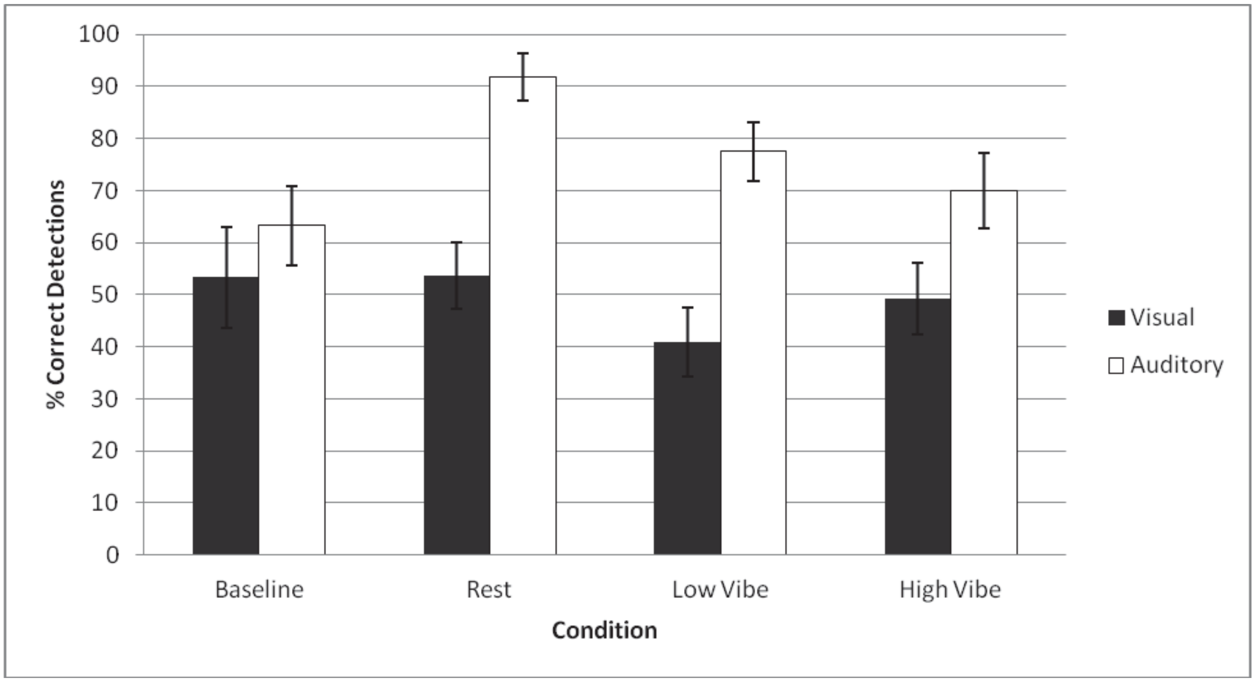

Figure 7: Cross-condition comparison of modality by percentage of correct detections (vigil 4).

The mean percentages of false alarms of critical signals in the final vigil are presented across conditions and modalities in Figure 8. The number of false alarms was greater in the visual modality (M = 0.58%) than in auditory modality (M = 0.33%). Although there was great variability in the number of false alarms in each condition, false alarm rates were low overall. The error bars show the standard error of the mean.

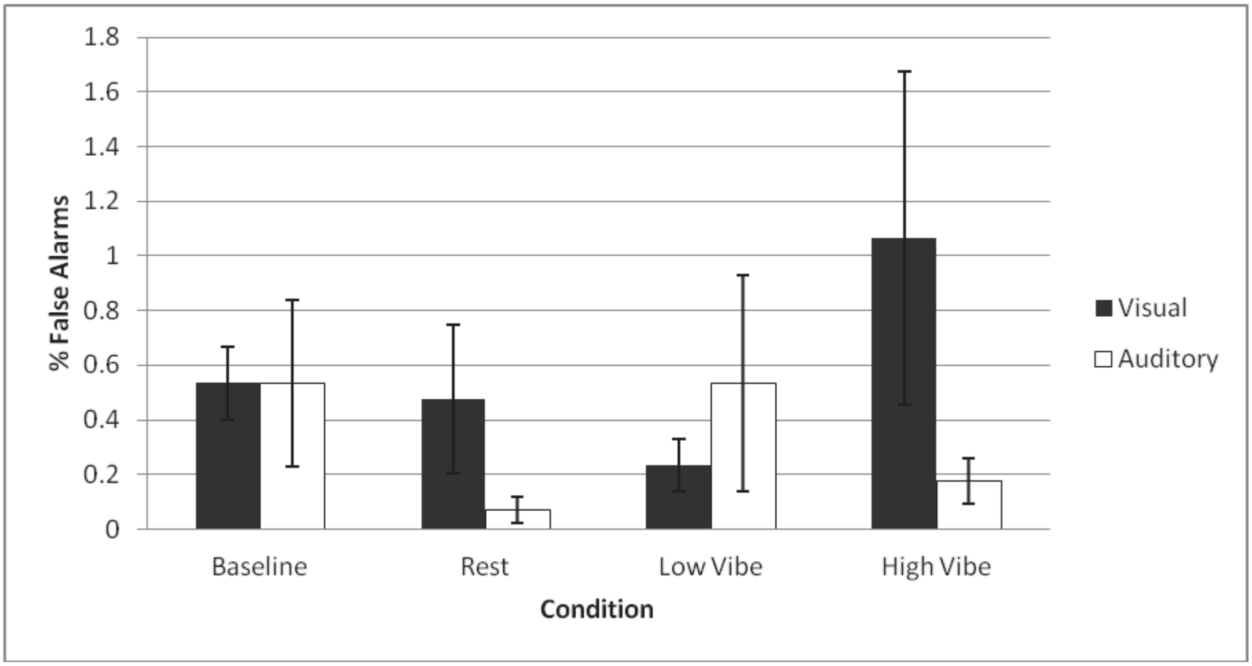

Figure 8: Cross-condition comparison of modality by percentage of false alarms (vigil 4).

3.3 Signal Detection Theory Measures

Signal Detection Theory (Tanner et al., 1954) is an analytical method that can be used to judge performance in signal detection tasks. These tasks test the ability of an operator to detect a critical signal among noise. The outcomes of a signal detection task are the hit (correct detection of the critical signal), miss, correct rejection, and false alarm (responding with a hit when no critical signal was present). Many factors (e.g. perceptual saliency) can affect an operator's ability to discern between a critical signal and noise.

3.3.1 Sensitivity

The index measure of sensitivity (denoted by d') allows experimenters to quantify an operator's performance in a signal detection task. In a vigilance experiment, sensitivity refers to the difference in the discrimination of the critical signal plus noise and noise for each specific operator. Mathematically, it is calculated as the difference between the means of the Gaussian distributions of the hit rate (ratio of hits to critical signals) and the false alarm rate (ratio of false alarms to non-critical signals). These results for Vigil 4 are presented in Figure below. The error bars show the standard error of the mean.

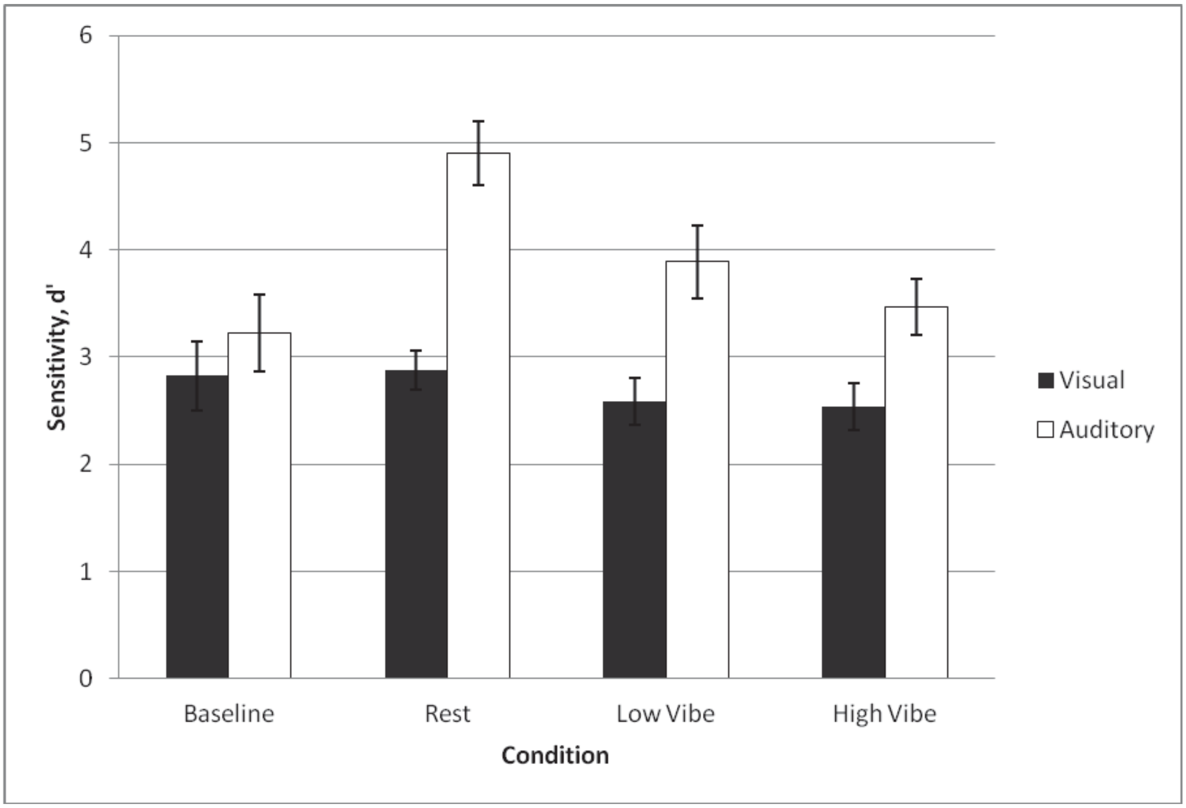

Figure 9: Cross-condition comparison of d' by modality (vigil 4).

The auditory modality showed a significantly higher sensitivity overall (M = 3.84) than the visual modality (M = 2.71), shown by a one-way ANOVA between sensory modalities, F(1,90)=28.62, $p < 0.0001$. In the visual modality, no significant differences were observed between any of the conditions. The auditory rest break countermeasure showed significantly greater performance than each of the other auditory conditions, F(7, 90) = 7.761, p<0.05. No other significant cross-condition interactions were found.

Cross-vigil comparisons of d’ for each experimental condition are shown in Figure 10 and Figure below for the visual and auditory modalities, respectively.

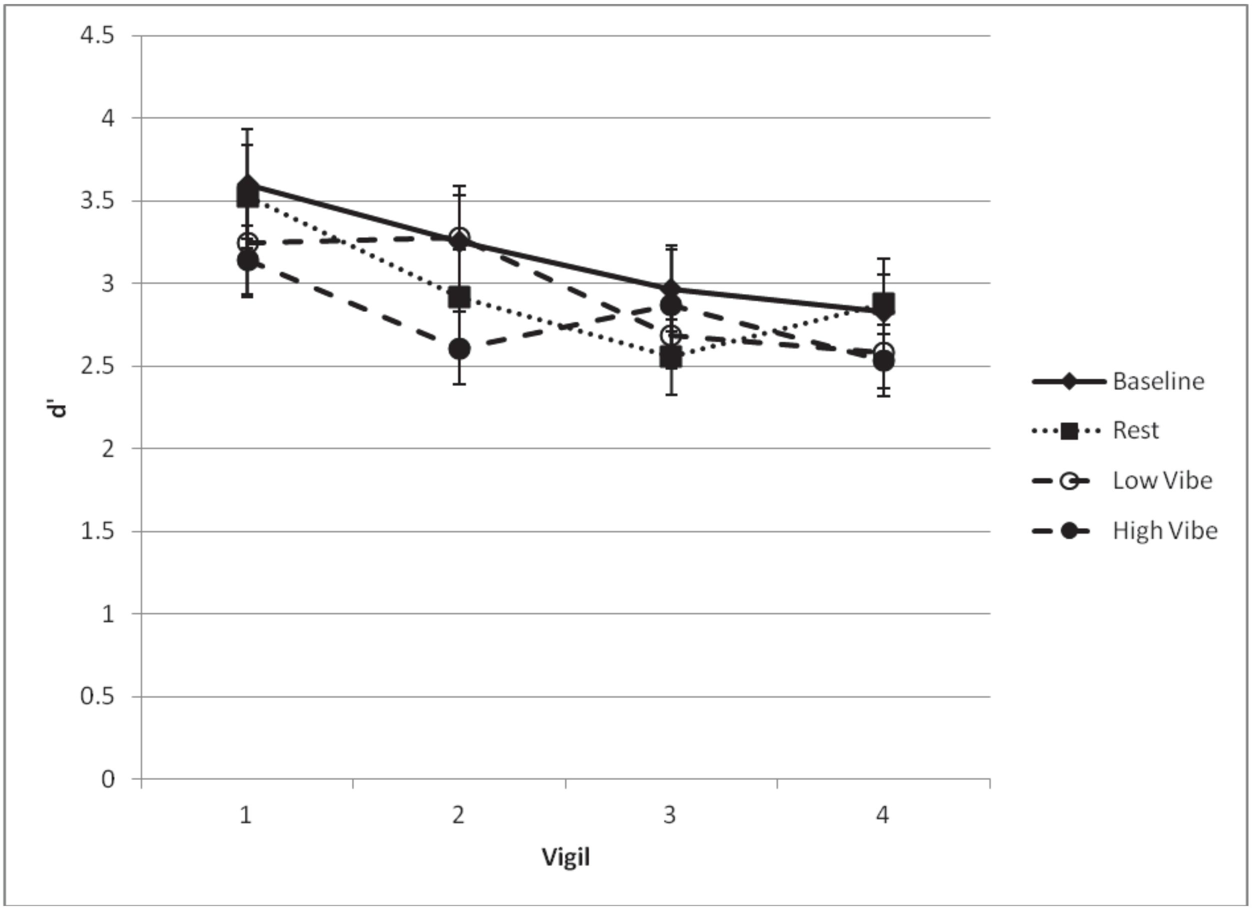

Figure 10: Cross-vigil comparison of d’ in the visual modality

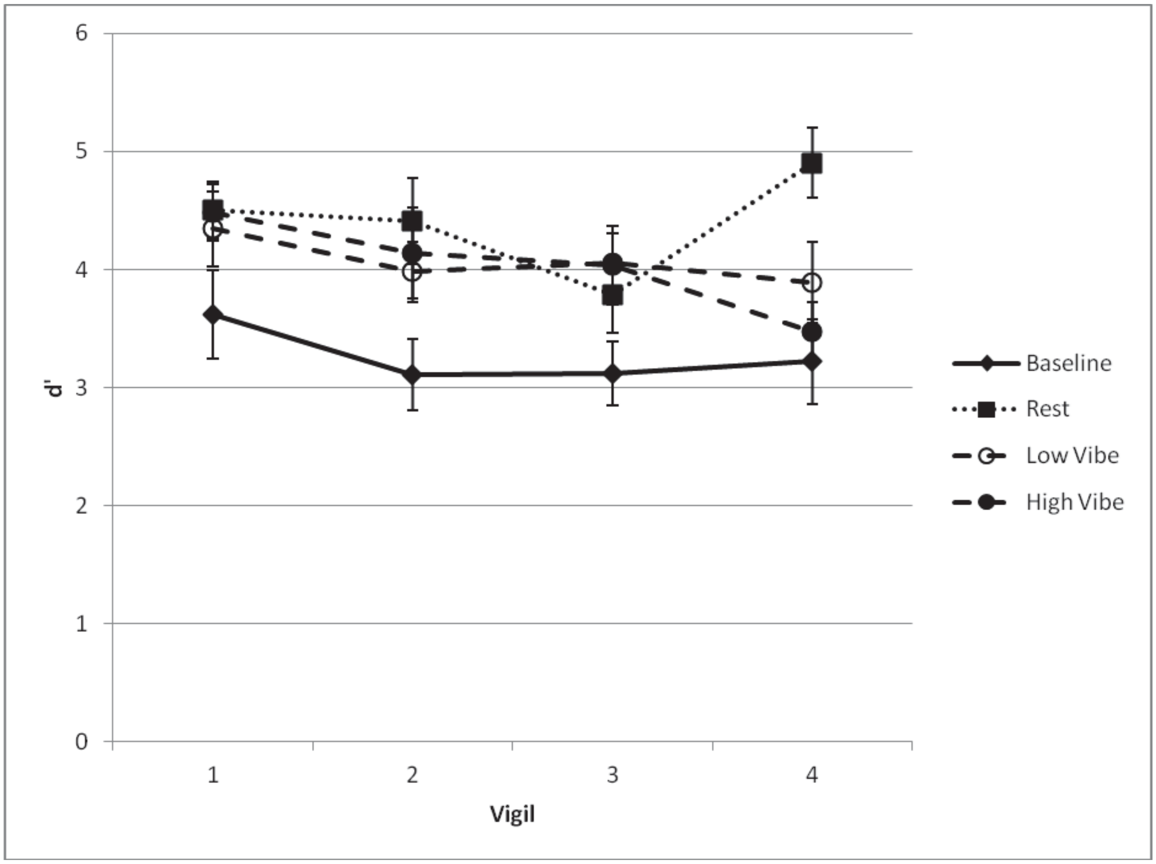

Figure 11: Cross-vigil comparison of d' in the auditory modality

Similar sensitivity levels were observed between the auditory and visual modalities in the baseline condition, with some divergence in the fourth vigil. There were no observable improvements in sensitivity due to the low and high vibrotactile (respectively) countermeasures applied in vigil four. No statistically significant differences were found between the different vibrotactile groups in their respective modalities ($p>0.05$).

3.3.2 Response Bias

The response bias, or criterion "c", is a measure of how likely a participant is to respond "signal present" to a presented signal. Furthermore, participants can assume liberal, balanced, or conservative strategies which are influenced by perceived target probabilities and which determine the probability of their responses.

Mathematically, the response bias is proportional (by a factor of -1/2) to the sum of the means of the Gaussian distributions of hit rate and false alarm rate. A response bias of zero occurs when false-alarm rates equal miss rates. Positive response bias values imply a tendency to respond "no signal" (conservative strategy) and negative values imply "signal present" (liberal strategy).

Figure 12 and Figure 13 below present the mean response biases for all conditions, across all four vigils, for the visual and auditory modalities, respectively. Response bias values were observed to be conservative (greater than 0) in all conditions and modalities. An increasing trend in response bias (e.g.

more conservative responses) was observed in both modalities. This may be attributed to subjects refining their expectations of target probability as the task progressed and they were exposed to a consistently low probability of target occurrence.

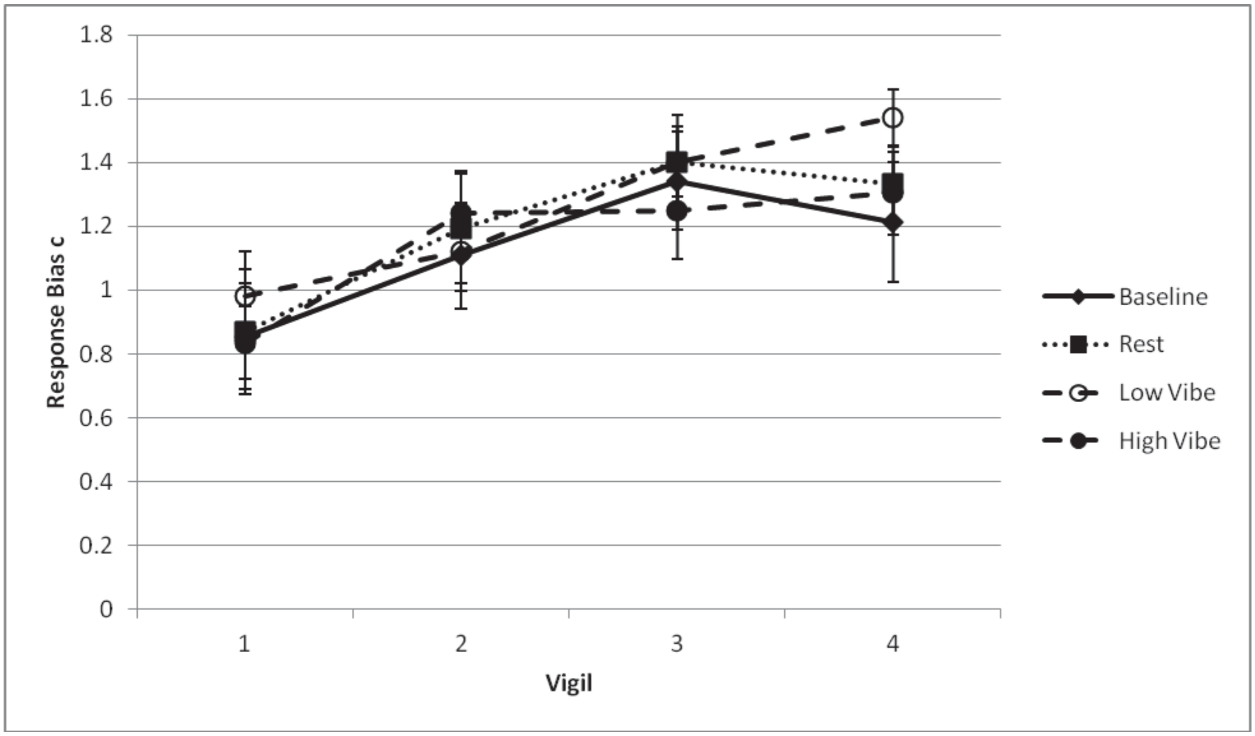

Figure 12: Response bias values for the visual modality

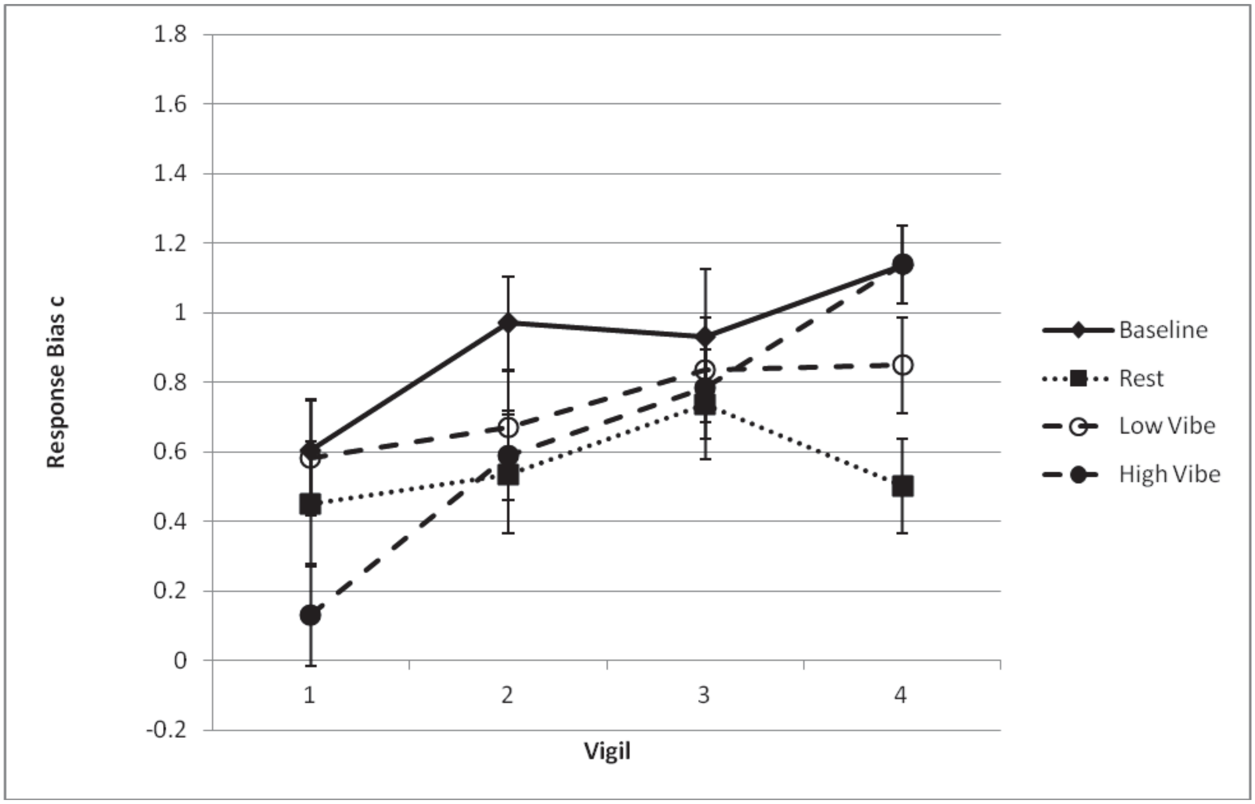

Figure 13: Response bias values for the auditory modality

3.3.3 Receiver Operating Characteristic

The ROC is another method of analyzing and visualizing sensitivity. ROC space is a two-dimensional graphical plot of false alarm rates on the x-axis and hit rate on the y-axis. Good performance is characterized by a high hit rate and a low false-alarm rate, making the top-left corner of the space the point of ideal or perfect performance. Figure 14 shows the average performance in vigil 4 of each of the eight experimental conditions plotted in ROC space. As the ROC plot shows, false alarm rates were similarly low for all groups. However, hit rate was greater for the auditory group and in particular for the rest break group.

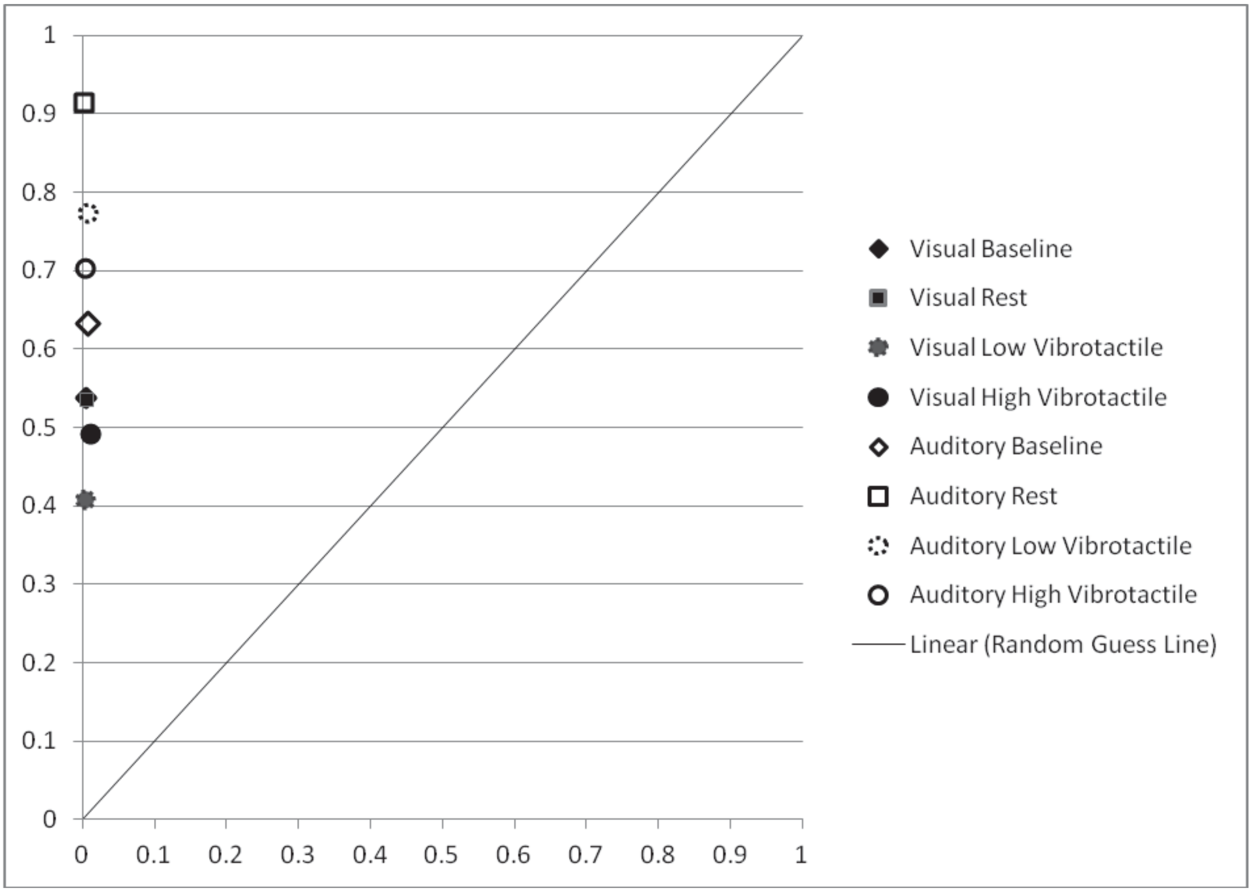

Figure 14: ROC plots of performance results in each experimental condition.

3.4 NASA-TLX Workload Measures

The NASA-TLX questionnaire requires a participant to numerically rate six workload-related categories and also to compare all unique pairs of categories to obtain a relative weighting of each category (Hart & Staveland, 1988). These categories are physical demand, mental demand, temporal demand, performance, frustration, and effort. The global workload score is then calculated as the weighted sum of all workload category ratings.

Weighted rating scores for each category of the NASA-TLX are presented in Figure 15 to observe the relative differences between the visual and auditory modalities. One observation worth noting is that the perceived physical demand in the visual modality (M=40.14) was more than twice the perceived demand in its auditory counterpart (M=15.33). This difference was significant based on a one-way ANOVA - F(1,90)=4.71, $p<0.05$. Also, the perceived temporal demand of the visual modality (137.20) was substantially greater than that of the auditory modality (M=88.25). This was also significant based on a one-way ANOVA – F(1,90)=5.49, $p<0.05$. The acronyms on the figure are as follows MD=Mental Demand, PD=Physical Demand, TD=Temporal Demand, OP=Performance, FR=Frustration level, EF=Effort level.

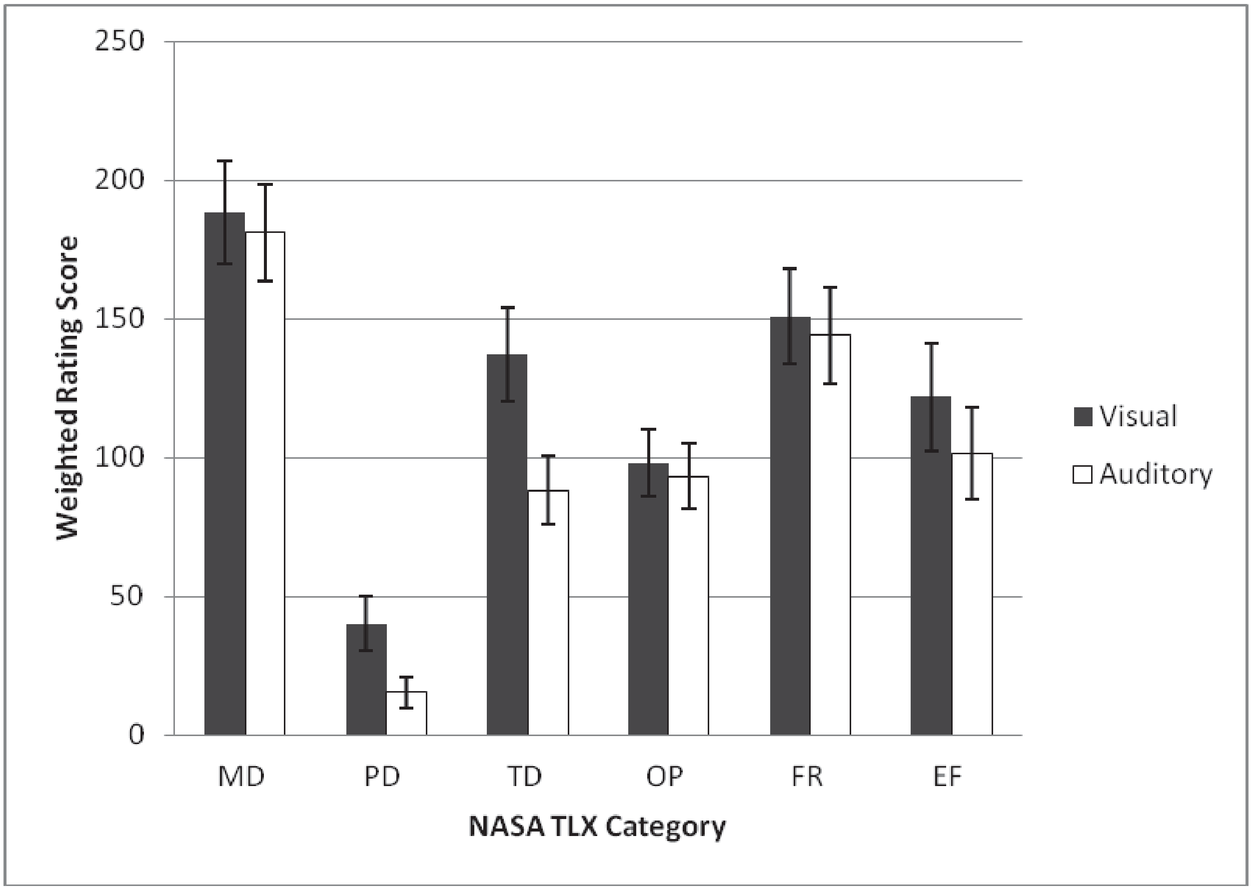

Figure 15: Cross-category comparison of weighted TLX Ratings by modality.

The global workload scores from the post-experiment NASA–TLX questionnaire were compared across modalities (Figure 16) and conditions (Figure 17).

Participants in the visual modality experienced a significantly greater perceived workload than in the auditory modality, as shown by a one-way ANOVA across sensory modalities, F(1,90)=6.18, $p<0.05$. Participants in the rest condition scored the lowest global workload values, but this was not significant.

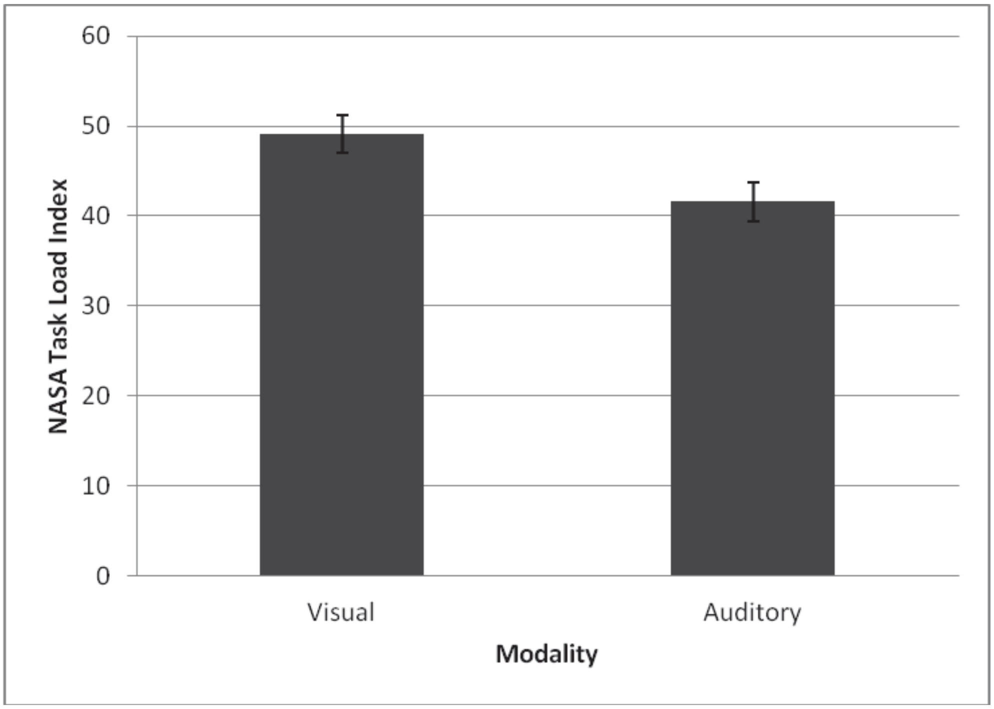

Figure 16: Cross-modality NASA-TLX comparison of global workload scores.

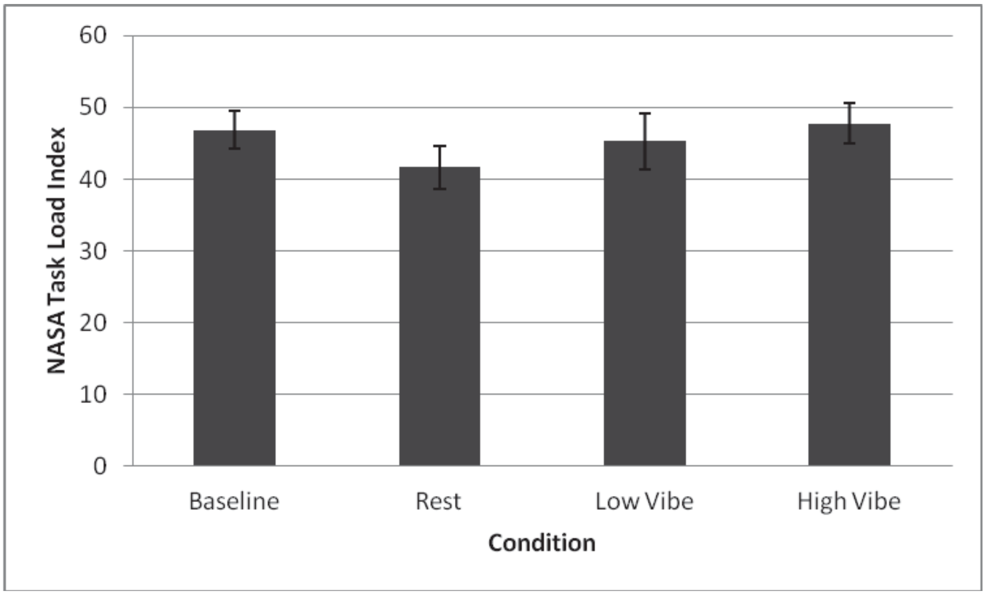

Figure 17: Cross-Condition TLX Comparison global workload scores.

3.5 Tactor Belt Annoyance Questionnaire

The means of the Tactile Annoyance Rating scores are presented for each tactile condition in Figure 18. The perceived tactile annoyance was rated out of five, with one being the lowest level of annoyance and five being the highest. The perceived tactile annoyance was low in both high and low vibrotactile conditions (averaged across both modalities)—the highest reported tactile annoyance rating was three, which was provided by only a single participant.

Participants in the high (70%) vibrotactile condition scored relatively higher on the annoyance rating (M = 1.46) than those in the low (30%) vibrotactile condition (M = 1.17), but this was not significant (p>0.05).

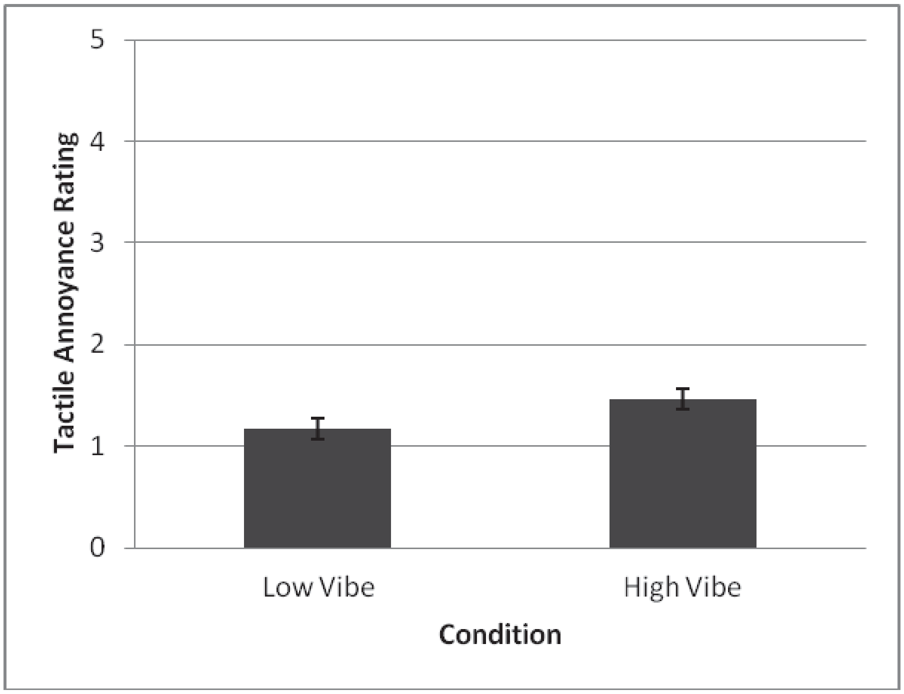

Figure 18: Cross-condition comparison of tactile annoyance rating.

3.6 Response Time

The average participant response times to the critical signals are presented in Figure 19. The error bars show the standard error of the mean. A two-way Modality x Countermeasure ANOVA based on the log transformation of the mean response time data found no significant response time differences between modalities or conditions, F(3, 90) = 1.249, p>0.05.

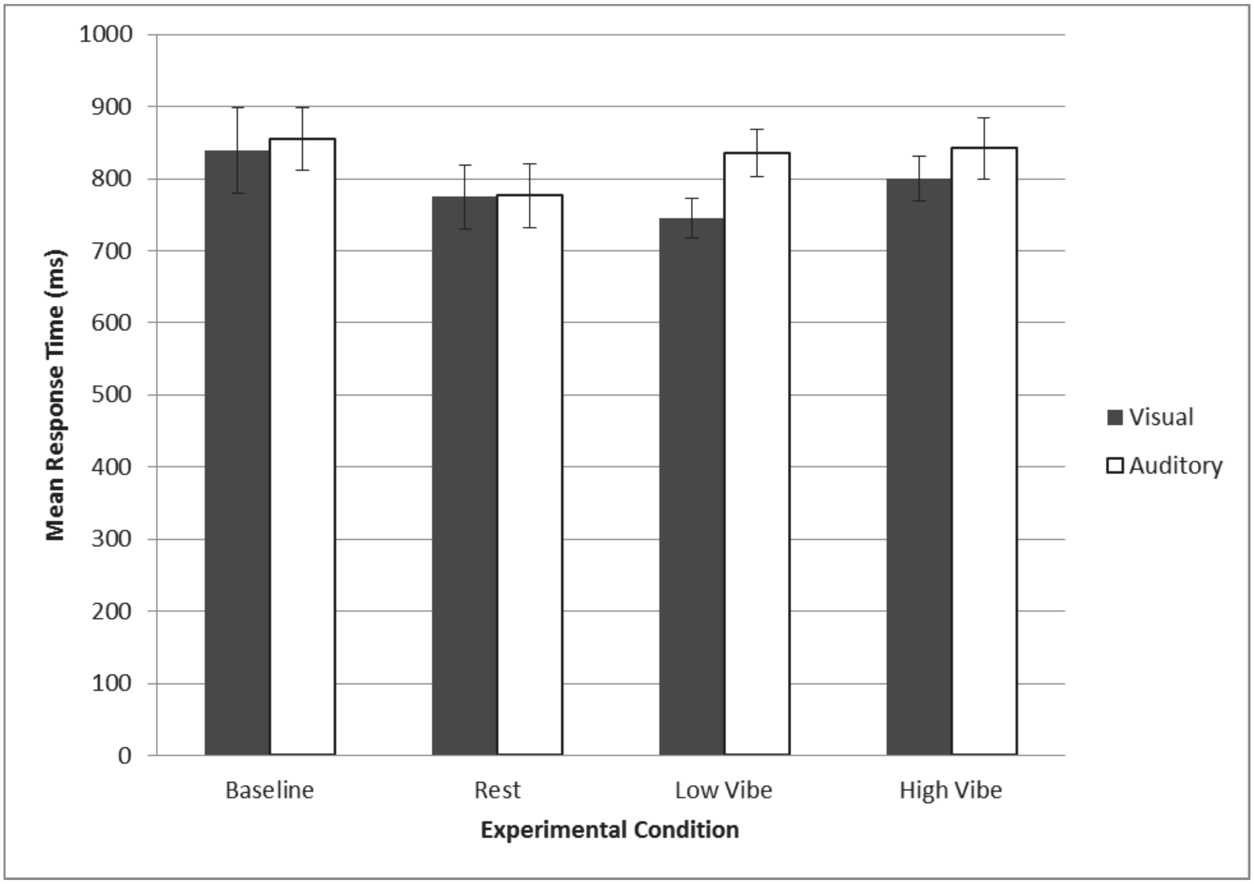

Figure 19: Cross-Condition Comparison of Mean Response Time by Condition.

4 Discussion

The analyses performed and presented on the experimental data were able to test all the hypotheses. Overall, the data validated prior findings in the vigilance literature regarding the existence of the vigilance decrement, performance and modality interactions, and the effectiveness of the rest break countermeasure in mitigating the vigilance decrement. This provides confidence in the experimental design and execution of the study. Significant cross modal effects were also observed, which is consistent with prior literature (Davies & Parasuraman, 1982; Szalma et al., 2004; Warm & Jerison, 1984). However, the vibrotactile stimuli did not show evidence of mitigating the vigilance decrement. The following are the findings regarding each hypothesis.

The first hypothesis appeared to be supported by the results. A vigilance decrement occurred in the first 30 minutes of all experimental conditions.

The second hypothesis appeared to be supported as well – participants in the visual modality conditions had consistently poorer performance than participants in the auditory modality conditions.

The third hypothesis was only partially supported – the rest break countermeasure group showed significantly better monitoring performance compared to the corresponding baseline group in the auditory modality but not in the visual modality.

The fourth hypothesis did not appear to be supported by the data. The vibrotactile countermeasure groups did not show improved performance compared to the corresponding baseline groups at this time.

The fifth hypothesis was not supported. No statistically significant differences were found between the different vibrotactile groups in their respective modalities.

The sixth hypothesis was partially supported. Monitoring performance for the rest break countermeasure condition was significantly different from that of the high vibrotactile countermeasure condition in the auditory modality, but no other significant interactions were found.

A vigilance decrement was observed in the first three vigils (30 minutes) of all the experimental conditions, providing confirmation that the experimental tasks did simulate a vigilance task. In correspondence with current theories, this decrement can be attributed to the attentional resource model of vigilance, caused by the loss of physiological arousal, which decreases the available information processing resources. There was no evidence in this study that contradicts the current theories and models of the vigilance decrement. Although the vigilance decrement had been previously attributed to a lack of attention and loss of arousal (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), Warm et al. (2008) argued that vigilance is a high workload task, which is demanding on information processing resources.

The comparisons of performance (by percentage of correct detections) showed substantial cross-modal differences. Signal detection performance in the auditory modality was better than in the visual modality, which is in general agreement with previous findings (Davies & Parasuraman, 1982; Szalma et al., 2004; Warm & Jerison, 1984). Szalma et al. (2004) attributed the superiority of the auditory modality to the decoupled nature of visual displays (i.e., perceiving the critical signals aurally even when the operator's eyes are directed elsewhere), which imposes less task demand than in a visual vigilance task (Galinsky et al., 1993).

The ability to sustain attention can be assessed through a comparison of measures at the final vigil between the various countermeasure groups and the baseline condition. According to this assessment, none of the vibrotactile conditions showed evidence of improving sustained attention in the final vigil. However, in the auditory modality, all countermeasures showed evidence of increased sensitivity. Furthermore, the performance levels for the final vigil of these conditions appear to be poorer than those of the preceding (third) vigils, suggesting that the vigilance decrement was not mitigated by the vibrotactile countermeasures. The rest break countermeasure conditions showed improvements in all three measures to mitigate the vigilance decrement, which was in general agreement with the effectiveness of rest break countermeasures (Colquhoun, 1959; Pigeau, Angus, O'Neill, & Mack, 1995).

Results from the NASA Task Load Index were similar to those gathered by Szalma et al. (2004), and showed that the vigilance task was a stressful and high workload task. Participants in the visual modality reported higher levels of stress than those in the auditory condition. There were also comments from some participants who found that sustaining visual attention was stressful on their eyes and expressed ergonomic discomfort from staring at the screen for a prolonged period. These findings are in agreement with those of Szalma et al. (2004), who also attributed the increased stress to postural and eye-strain discomfort. The larger temporal demand in the visual modality may suggest that there was a lack of compensation for the differences in cross-modal temporal discrimination (Szalma et al., 2004) when designing the critical signal durations for each modality.

Physiological arousal itself has been attributed to the flow of blood in the right cerebral hemisphere of the brain and has been related to the attentional resource model of vigilance (Hitchcock et al., 2003). It has also been shown that vibrotactile stimulation causes increased cerebral blood flow through the human somatosensory system (Meyer, et al., 1991). As a result, sufficient vibrotactile stimulation should increase one’s physiological arousal, increasing the availability of attentional resources. However, we did not find evidence that vibrotactile signals result in an increased arousal. The rather low ratings on the tactile annoyance questionnaire, as well comments from participants who reported that they could hardly feel the vibrations during the final vigil, and also the poor performance of the vibrotactile stimuli as countermeasures, taken together, may suggest that the signal strength (i.e., amplitude) of the vibrotactile stimulation plays a large role in the amount of physiological arousal it causes. Higher perceived amplitude of vibrotactile sensation coupled with a low signal frequency may be the optimal method to induce physiological arousal for a sustained attention task.

5 Conclusions

Overall, a vigilance decrement was found in all the conditions of the study, with no support for the effectiveness of vibrotactile countermeasures as a means to combat the vigilance decrement. This was attributed to the effect of physiological arousal on the available information processing resources.

The study supported the ability of the rest break countermeasure to mitigate the vigilance decrement in both the auditory and visual modalities for a vigilance task. Performance in the auditory modality was better than that of the visual modality in all conditions, consistent with prior results in the literature.

The study also supported the existing literature confirming that vigilance tasks have high workload demands.

Although this particular study did not find significant evidence for the efficacy of vibrotactile stimulation in sustaining attention, existing literature shows promise for further experimentation – there are further dimensions of vibrotactile stimulation (such as amplitude and exposure) which could help to sustain attention and may be worthy of investigation.

References

Arrabito, R. G., Ho, G., Aghaei, B., & Burns, C. (2011). Effects of vibrotactile stimulation for sustaining performance in a vigilance task: A pilot study. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55*, 1160-1164.

Bergum, B. O. & Lehr, D. J. (1963). Effects of authoritarianism on vigilance performance. *Journal of Applied Physiology, 66*, 383-385.

Bruck, D., & Thomas, I. R. (2009). Smoke alarms for sleeping adults who are hard-of-hearing: Comparison of auditory, visual, and tactile signals. *Ear & Hearing, 30*, 73-80.

Caggiano, D. M., & Parasuraman, R. (2004). The role of memory representation in the vigilance decrement. *Psychonomic Bulletin & Review*, *11*, 932-7.

Cheung, B., van Erp, J. B. F., & Cholewiak, R. W. (2008). Anatomical, neurophysiological and perceptual issues of tactile perception. In J. B. F. van Erp, & B. P. Self (Eds.), *Tactile Displays For Orientation, Navigation and Communication in Air, Sea and Land Environments* (Report No. TR-HFM-122, pp. 2-1–2-18). Neuilly-sur-Seine Cedex, France: North Atlantic Treaty Organization, Research and Technology Organization.

Cholewiak, R. W., Brill, J. C., & Schwab, A. (2004). Vibrotactile localization on the abdomen: Effects of place and space. *Perception & Psychophysics*, *66*, 970-987.

Colquhoun, W. V. (1959). The effect of a short rest pause on inspection efficiency. *Ergonomics*, *2*, 367-372.

Colquhoun, W. V. (1961). The effect of “unwanted” signals on performance in a vigilance task. *Ergonomics*, *4*, 41-51.

Colquhoun, W. P., & Baddeley, A. D. (1964). Role of pretest expectancy in vigilance decrement. *Journal of Experimental Psychology*, *68*(2), 156-160.

Davenport, W. G. (1974). Arousal theory and vigilance: Schedules for background stimulation. *Journal of General Psychology, 91*, 51-59.

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

Finomore, V., Matthews, G., Shaw, T., & Warm, J. (2009). Predicting vigilance: A fresh look at an old problem. *Ergonomics*, *52*, 791-808.

Floru, R., Cail, F., & Elias, R. (1985). Psychophysiological changes during a VDU repetitive task. *Ergonomics*, *28*, 1455-1468.

Frankmann, J. P., & Adams, J. A. (1962). Theories of Vigilance. *Psychological Bulletin*, *59*, 257-72.

Fraser, D. C. (1953). The relation of an environmental variable to performance in a prolonged visual task. *Quarterly Journal of Experimental Psychology*, *5*, 31-32.

Galinsky, T. L., Rosa, R. R., Warm, J. S., & Dember, W. N. (1993). Psychophysical determinants of stress in sustained attention. *Human Factors, 43,* 349-359.

Gardner, L. W., Eugene, R., & Margaret, J. R. (2007). *Comparison of football shaped rumble strips versus rectangular rumble strips.* (Rep. No. K-tran: KSU-00-4P2). Manhattan, KS: Kansas State University, Department of Industrial and Manufacturing Systems Engineering.

Gescheider, G. A. (1997). *Psychophysics: The fundamentals* (3rd ed.). Mahwah, NJ: Erlbaum.

Green, D. M., & Swets, J. A. (1966). *Signal Detection Theory and Psychophysics*. New York, NY: John Wiley & Sons.

Grier, R. A, Warm, J. S., Dember, W. N., Matthews, G., Galinsky, T. L., & Parasuraman, R. (2003). The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Human Factors*, *45*, 349-59.

Gunn, D. V., Studios, M. G., Warm, J. S., Nelson, W. T., Bolia, R. S., & Force, A. (2005). Target acquisition with UAVs: Vigilance displays and advanced cuing interfaces. *Human Factors, 47*, 488-497.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock, & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). Amsterdam, Holland: North-Holland.

Helton, W. S., Hollander, T. D., Warm, J. S., Matthews, G., Dember, W. N., Wallaart, M., Beauchamp, G., Parasuraman, R., & Hancock, P. A. (2005). Signal regularity and the mindlessness model of vigilance. *British Journal of Psychology, 96,* 249-61

Helton, W. S., Matthews, G., & Warm, J. S. (2009). Stress state mediation between environmental variables and performance: the case of noise and vigilance. *Acta Psychologica*, *130*, 204-13.

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 Ergonomics Science*, *4*, 89-112.

Ho, C., Reed, N., & Spence, C. (2007). Multisensory in-car warning signals for collision avoidance. *Human Factors*, *49*, 1107-1114.

Johnson, A., & Proctor, R. W. (2004). *Attention: Theory and Practice* (pp. 257-259). Thousand Oaks, CA: Sage Publications.

Koelega, H. S., Brinkman, J., & Bergman, H. (1986). No effect of noise on vigilance performance? *Human Factors*, *28*, 581-593.

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.

Mackworth, N. H. (1950). *Researches on the measurement of human performance* (Special Report Series No. 268). London, UK: Medical Research Council, H. M. Stationery Office.

Mackworth, J. F. (1968). Vigilance, arousal, and habituation. *Psychological Review*, *75*, 308-22.

Matthews, G. (2001). Individual differences in energetic arousal and sustained attention: A dual-task study. *Personality and Individual Differences, 31,* 575-589.

Matthews, G., Davies, D. R., & Holley, P. J. (1990). Arousal and visual sustained attention: The role of resource availability. *Personality and Individual Differences, 11,* 1159-1173.

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

McCormack, D. (1959). Performance in vigilance task with and without knowledge of results. *Canadian Journal of Psychology, 13*, 68-71.

Meyer, E., Ferguson, S. S., Zatorre, R. J., Alivisatos, B., Marrett, S., Evans, A. C., & Hakim, A. M. (1991). Attention modulates somatosensory cerebral blood flow response to vibrotactile stimulation as measured by positron emission tomography. *Annals of Neurology, 29,* 440-3.

Mortimer, B., Zets, G., & Cholewiak, R. (2007). Vibrotactile transduction and transducers. *Journal of the Acoustical Society of America*, *121*, 2970-2977.

Osborn, W. C., Sheldon, R. W., & Baker, R. A. (1963). Vigilance performance under conditions of redundant and nonredundant signal presentation. *Journal of Applied Psychology, 47,* 130-134.

Parasuraman, R. (1986). Vigilance, monitoring, and search. In K. Boff, L. Kaufaman, & J. Thomas (Eds.), *Handbook of Perception and Human Performance, Vol. 2. Cognitive Processes and Performance* (pp. 43.1-43.39). New York, NY: Wiley.

Parasuraman, R., Molloy, R., Mouloua, M., & Hilburn, B. (1996). Monitoring of automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and Human Performance* (pp. 91-115). Mahwah, NJ: Lawrence Erlbaum Press.

Pigeau, R. A., Angus, R. G., O'Neill, P., & Mack, I. (1995). Vigilance latencies to aircraft detection among NORAD surveillance operators. *Human Factors*, *37*, 622-634.

Pope, A. T., & Bogart, E. H. (1992). Identification of hazardous awareness states in monitoring environments. *Journal of Aerospace*, *101*, 448-457.

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.

Ruff, H. A. (2004). Exploring automation issues in supervisory control of multiple UAVs. *Technology* (pp. 218-222).

Schmidt, E. A, Schrauf, M., Simon, M., Fritzsche, M., Buchner, A., & Kincses, W. E. (2009). Drivers' misjudgement of vigilance state during prolonged monotonous daytime driving. *Accident; Analysis and Prevention*, *41*(5), 1087-93.

Szalma, J., Warm, J., Matthews, G., Dember, W., Weiler, E., Meier, A., & Eggemeier, F. T. (2004). Effects of sensory modality and task duration on performance, workload, and sustained attention. *Human Factors, 42*, 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*, 183-94.

Thackray, R. I. (1981). The stress of boredom and monotony: A consideration of the evidence. *Psychosomatic Medicine*, *43*, 165-176.

Thackray, R. I., Bailey, J. P., & Touchstone, R. M. (1979). The effect of increased monitoring load on vigilance performance using a simulated radar display. *Ergonomics*, *22*, 529-539.

Thompson, W., Lopez, N., Hickey, P., DaLuz, C., Caldwell, J. L., & Tvaryanas, A. P. (2006). *Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (OP-REPAIR)* (Report No. HSW-PE-BR-TR-2006-0001). Brooks City-Base, TX: United States Air Force, 311th Human Systems Wing.

Warm, J. S. (1984). An Introduction to vigilance. In J. S. Warm (Ed.), *Sustained Attention in Human Performance* (pp. 1-14). Toronto, ON: John Wiley and Sons.

Warm, J. S., Dember, W. N., & Parasuraman, R. (1991). Effects of olfactory stimulation on performance and stress in a visual sustained attention task. *Journal of the Society of Cosmetic Chemists*, *42*, 199-210.

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

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*(5), 459-482.

Annex A Cross Modality Matching Procedure

This appendix describes a cross modality matching procedure (Gescheider, 1997) that will be carried out by each participant assigned to the auditory monitoring task. Participants will adjust the strength of the auditory signal so that its perceived loudness will match the perceived brightness of a fixed visual signal. The result of the procedure will equate the discrimination difficulty of the auditory task (section 5.5.1) and visual task (section 5.5.2) for each participant.

A.1 Stimuli

A.1.1 Auditory

The auditory stimulus will be the auditory non-critical signal (section 5.2.1). Its intensity can be adjusted in 1dB increments between the range of 49 - 69 dB SPL.

A.1.2 Visual

The visual stimulus will be the visual non-critical signal (section 5.2.2). Its luminance will remain at a fixed level of 17.5 cd/m2.

A.2 Tasks

Participants will be required to match the apparent loudness of the auditory non-critical signal (section 5.2.1) to the apparent brightness of the non-critical visual signal (section 5.2.2). The fixed visual signal will be presented at 17.5 cd/m2. A variable auditory signal will be presented following the offset of the visual signal within the range of 49-69 dB SPL. Participants' task is to adjust the perceived loudness of the auditory signal to the perceived brightness of the visual symbol using the computer keyboard's up and down arrow keys. Participants will press the space bar key to log the match.

A.3 Procedure

Prior to the task, participants will be presented with the quietest and loudest auditory non-critical signals, which will serve as anchor points.

For the task, participants will carry out 12 trials. Each trial consists of the presentation of the fixed visual signal followed by the presentation of the variable auditory signal. The variable auditory signal will be initially presented at a random level within the allowable dynamic range. Participants will press the up and down arrows on the computer keyboard to change the dB level of the variable signal in 1dB increments. The visual and auditory signals will be repeated until participants perceive that the intensity of the variable auditory signal matches the perceived intensity of the fixed visual signal, which participants will indicate by pressing the space bar. After pressing the space bar, the trial is complete and participants must match a new random variable auditory signal to the fixed visual signal.

Annex B DRDC Toronto Volunteer Consent Form

Protocol Number: #L-753
Research Project Title: Vibrotactile Countermeasure for Mitigating the Vigilance Decrement for UAV Operators
Principal Investigator: G. Robert Arrabito, ***DRDC Toronto***
Co-Investigators: Geoffrey Ho, ***DRDC Toronto***
Catherine Burns, ***University of Waterloo***

I, ______________________ (name) of ___________________________________ (address and phone number) hereby volunteer to participate as a subject in the study "Vibrotactile Countermeasure for Mitigating the Vigilance Decrement for UAV Operators" (Protocol #L-753). I have read the information package on the research protocol, and have had the opportunity to ask questions of the Investigator. All of my questions concerning this study have been fully answered to my satisfaction. However, I may obtain additional information about the research project and have any questions about this study answered by contacting one or more of the following individuals:

Robert Arrabito at 416-635-2033; Robert.Arrabito@drdc-rddc.gc.ca.
Catherine Burns at 519-888-4567 (x34904); c4burns@uwaterloo.ca.

I have been told that prior to the experimental session, I will be required to surrender any wristwatch, pager and/or cell phone to prevent distractions while carrying out the study. I have been told that I will be asked to participate in one experimental session having a total duration of two (2) consecutive hours, and that this experimental session will be divided into three (3) parts:
<u>Part 1 – Cross Modality Matching Procedure</u>: I will be presented with signals in the auditory and visual modality. My task will be to adjust the perceived intensity of a signal in one modality to match the perceived intensity of a signal in the other modality. This will be repeated several times.
<u>Part 2 – Vigilance Monitoring Task</u>: I will be presented with signals in the auditory or visual modality. My task will be to monitor the signals and to detect signals which are of shorter duration. I understand that after familiarization with the stimuli I will be given at most two (2) attempts to meet a preset criterion in a training session. If I do not meet the preset criterion in the training session then I will be replaced in the study. I will be required to wear headphones and a tactor belt.
<u>Part 3 – Questionnaires</u>: I will be required to complete a series of questionnaires.

For both parts 1 & 2, the sound pressure level (SPL) from the headset will not exceed 69 dB SPL, which is well below the maximum at-ear noise level of 87 dBA for an eight hour period of exposure as specified by the Canada Labour code. Additionally, vibrotactile signals presented on my waist will result in very low peak accelerations that are orders of magnitude below the suggested limits for human exposure (as described in standards and directives such as EU 2002/44/EC). I have been told that this is a minimal risk study and that the principal risks of the research protocol are normal levels of eye strain and muscular discomfort from sitting for a prolonged period gazing at the computer monitor. I acknowledge that my participation in this study, or indeed any research, may involve risks that are currently unforeseen by Defence Research and Development Canada (DRDC).

I understand that my experimental data will be protected under the Government Security Policy (GSP) at the appropriate designation and not revealed to anyone other than the DRDC-affiliated Investigator(s) or external investigators from the sponsoring agency without my consent except as data unidentified as to source.

I understand that my name will not be identified or attached in any manner to any publication arising from this study. Moreover, I understand that the experimental data may be reviewed by an internal or external audit committee with the understanding that any summary information resulting from such a review will not identify me personally.

I understand that, as a Government Institution, DRDC is committed to protecting my personal information. However, under the Access to Information Act, copies of research reports and research data (including the database pertaining to this project) held in Federal government files, may be disclosed. I understand that prior to releasing the requested information, the Directorate of Access to Information and Privacy (DAIP) screens the data in accordance with the Privacy Act in order to ensure that individual identities (including indirect identification due to the collection of unique identifiers such as rank, occupation, and deployment information of military personnel) are not disclosed.

I understand that I am free to refuse to participate and may withdraw my consent without prejudice or hard feelings at any time. Should I withdraw my consent, my participation as a subject will cease immediately, unless the Investigator(s) determine that such action would be dangerous or impossible (in which case my participation will cease as soon as it is safe to do so). In this case I will have the option of requiring that any data that I have provided be destroyed. I also understand that the Investigator(s) or their designate may terminate my participation at any time, regardless of my wishes

I have been informed that the research findings resulting from my participation in this research project may be used for commercialization purposes.

I understand that for my participation in this research project, I am entitled to remuneration in the form of a stress allowance. I will receive a stress allowance of $40.40 if I complete the entire research project, $3.00 if I do not complete Part 1 of the experiment, $5.00 if I fail to meet the training performance criteria for the monitoring task in Part 2, or $7.00 if I fail to complete Part 2 of the experiment after meeting the monitoring training performance criteria. Stress remuneration is taxable. T4A slips are issued only for amounts in excess of $500.00 paid during a calendar year.

I have informed the Principal Investigator that I am currently a subject in the following other DRDC Toronto research project(s): ____ (cite Protocol Number(s) and associated Principal Investigator(s)), and that I am participating as a subject in the following research project(s) at institutions other than DRDC Toronto: ____ (cite name(s) of institution(s))

I understand that by signing this consent form I have not waived any legal rights I may have as a result of any harm to me occasioned by my participation in this research project beyond all risks I have assumed.

Name of Volunteer: ____

Signature of Volunteer: _____________________________________ Date: ____________

Name of Witness to Signature: ____

Signature of Witness: ______________________________________ Date: ____________

Family Member or Contact Person (name, address, daytime phone number & relationship) ____

Principal Investigator: ____

Signature of Principal Investigator: ______________________________ Date: _____________

FOR SUBJECT ENQUIRY IF REQUIRED:

Should I have any questions or concerns regarding this project **before, during, or after** participation, I understand that I am encouraged to contact Defence R&D Canada - Toronto (DRDC Toronto), P.O. Box 2000, 1133 Sheppard Avenue West, Toronto, Ontario M3M 3B9. This contact can be made by surface mail at this address or in person, by phone or e-mail, to any of the DRDC Toronto numbers and addresses listed below:

- Principal Investigator: Mr. G. Robert Arrabito, (416) 635-2033, Robert.Arrabito@drdc-rddc.gc.ca

- Chair, DRDC Human Research Ethics Committee (HREC): Dr. Jack P. Landolt, (416) 635-2120, Jack.Landolt@drdc-rddc.gc.ca

I understand that I will be given a copy of this consent form so that I may contact any of the above-mentioned individuals at some time in the future should that be required.

Annex C Recruitment Poster

Participants Required

for a study investigating the efficacy of vibrotactile signals for sustaining performance in a monitoring task

Participants:

- Male & female 18 - 60 years of age.
- Self-reported normal hearing and normal or corrected to normal vision.

Compensation:

Subjects will be given a stress allowance in accordance with guidelines established by Defence Research and Development Canada.

Location of Experiment:

University of Waterloo – Advanced Interface Design Laboratory
Building E2; Rm 1303N

Procedure:

Subjects will be required to perform either an auditory or visual monitoring task. The total duration of the study will be two (2) consecutive hours.

Benefits of the Study:

- Improve understanding of the efficacy of a vibrotactile countermeasure for sustaining performance in auditory and visual monitoring tasks.
- Potentially allow researchers to suggest a novel method to improve crew performance in controlling uninhabited aerial vehicles.

Risks:

This is a minimal risk study. Participants may experience normal levels of eye strain and muscular discomfort from sitting for a prolonged period gazing at the computer monitor.

Contact:

Interested volunteers should contact (study leader) at (telephone number) or (email address). [To be determined]

Annex D Annoyance Rating of Vibrotactile Signals

To be completed by the Experimenter:

Date and Time: ________________________________

Participant's ID: __________________________________

To be completed by the Participant:

We would like to get your opinion on annoyance level of the vibrotactile signals. The provided scale ranges from **no annoyance** to **substantial annoyance**. However, rest assured that the vibrotactile signals presented on your waist result in very low peak accelerations that are orders of magnitude below the suggested limits for human exposure (as described in standards and directives such as EU 2002/44/EC).

On a scale of one (1) to five (5) rate the **annoyance of vibration** with

1 = no annoyance

2 = very slight annoyance

3 = slight annoyance

4 = moderate annoyance

5 = substantial annoyance

(Circle one)

Vibration: **1** **2** **3** **4** **5**

General Comments

Likes

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____

____

Dislikes

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____

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Suggestions for Improvement

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____

____

Other

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Annex E Participant Information Package (Auditory Monitoring Task)

Title: Vibrotactile Countermeasure for Mitigating the Vigilance Decrement for UAV Operators
Principal Investigator: G. Robert Arrabito, DRDC Toronto
Co-Investigators: Geoffrey Ho, DRDC Toronto
Catherine Burns, University of Waterloo

Background
Uninhabited Aerial Vehicles (UAVs) are aircraft systems without the onboard presence of a pilot or crew. Military organizations, including the Canadian Forces (CF), are using UAVs to play an increasing role in providing intelligence, surveillance and reconnaissance (ISR). To help improve ISR capability, one area of research that requires investigation is the development of methods that could sustain "acceptable" performance levels in monitoring tasks over prolonged periods. This could be particularly useful for UAV crews.

Your Tasks
You will be participating in one (1) session lasting two (2) consecutive hours. You will complete the study in a quiet room. There are three (3) tasks for you to complete. Before commencing, we ask that you surrender any wristwatch, cell phone, pager, and other electronic devices to prevent distractions while carrying out the study. Before placing them inside a provided box, these items must be **turned off**. You can keep the box beside you during the course of the study. Please indicate if you have any of the following with you at the moment.

Wristwatch	☐ Yes	☐ No
Cell Phone	☐ Yes	☐ No
Pager	☐ Yes	☐ No
Other electronic devices	☐ Yes	☐ No

Task #1
For the duration of this task, you will wear headphones. A small rectangle at a certain level of brightness will flash at the centre of the computer monitor. After you see the rectangle, you will hear a burst of white noise (a hissing sound) over your headphones, set at a random noise level. Your task is to adjust the loudness of the white noise burst until you believe that its loudness seems equal to the brightness of the rectangle. You will be able to adjust the volume of the white noise burst louder and quieter using the up and down arrows on the computer keyboard. There is no right or wrong answer, this decision is based on your own perception. There is also no time limit for you to make a match. Once you feel that the loudness and brightness seem equal, you will then press the space bar key. Subsequently, a new rectangle will be presented on the computer monitor, along with a new noise burst for you to adjust. This process will be repeated several times. You will have an opportunity to practice the task before the experiment begins.
Task #2

For the duration of this task, you will wear headphones and a tactor belt. The belt has eight (8) sensors that vibrate like a cell phone in vibrate mode. You will be given an opportunity prior to the experiment to familiarize yourself with the vibrotactile signals. However, the vibrotactile signals **may** or **may not** be presented throughout the experiment.

You will complete an auditory monitoring task that will not exceed the time allotted for this study. A repetitive burst of white noise (a hissing sound) will be presented over your headphones. There are two types of noise bursts which differentiate between critical signals and non-critical signals. The critical signals will be slightly **shorter in duration** than the non-critical signals. Your job will be to press the red button on the subject response pad with your preferred hand immediately after you hear a critical signal. If you do not hear a critical signal, then do not press the red button on the subject response pad. Do not sacrifice accuracy for speed. A noise burst will be continuously presented so you will be required to continuously monitor for the presentation of critical signals. You will have an opportunity to practice the task. Before the experiment begins, you will carry out a training session to ensure you understand the task. You will be given at most two (2) attempts to meet this criterion. If you do not meet the preset criterion in the training session then you will be replaced in the study.

Task #3

You will be required to complete a series of questionnaires.

Benefits of the Study

You will have the opportunity to experience a task that simulates a real-world monitoring task. The results from this study will help increase our understanding of various methods to sustain performance in visual and auditory monitoring tasks. This may lead to improvements in the operational effectiveness of Canadian Forces' UAV operating crew.

Risks

This is a minimal risk study. During the session, you may experience normal levels of eye strain and muscular discomfort from sitting for a prolonged period gazing at the computer monitor. The level of the sound is well below the maximum permissible exposure as set out by the Canada Labour Code. The vibrotactile signals presented on your waist result in very low peak accelerations that are orders of magnitude below the suggested limits for human exposure (as described in standards and directives such as EU 2002/44/EC). *Any questions?*

Annex F Participant Information Package (Visual Monitoring Task)

Title: Vibrotactile Countermeasure for Mitigating the Vigilance Decrement for UAV Operators
Principal Investigator: G. Robert Arrabito, DRDC Toronto
Co-Investigators: Geoffrey Ho, DRDC Toronto
Catherine Burns, University of Waterloo

Background

Uninhabited Aerial Vehicles (UAVs) are aircraft systems without the onboard presence of a pilot or crew. Military organizations, including the Canadian Forces (CF), are using UAVs to play an increasing role in providing intelligence, surveillance and reconnaissance (ISR). To help improve ISR capability, one area of research that requires investigation is the development of methods that could sustain "acceptable" performance levels in monitoring tasks over prolonged periods. This could be particularly useful for UAV crews.

Your Tasks

You will be participating in one (1) session lasting two (2) consecutive hours. You will complete the study in a quiet room. There are two (2) tasks for you to complete. Before commencing, we ask that you surrender any wristwatch, cell phone, pager, and other electronic devices to prevent distractions while carrying out the study. Before placing them inside a provided box, these items must be **turned off**. You can keep the box beside you during the course of the study. Please indicate if you have any of the following with you at the moment.

Wristwatch	☐ Yes	☐ No
Cell Phone	☐ Yes	☐ No
Pager	☐ Yes	☐ No
Other electronic devices	☐ Yes	☐ No

Task #1

For the duration of this task, you will wear headphones and a tactor belt. The belt has eight (8) sensors that vibrate like a cell phone in vibrate mode. You will be given an opportunity prior to the experiment to familiarize yourself with the vibrotactile signals. However, the vibrotactile signals **may** or **may not** be presented throughout the experiment.

You will complete a visual monitoring task that will not exceed the time allotted for this study. A white horizontal bar will be repetitively presented in the middle of the computer monitor. There are two types of horizontal bars which differentiate between critical signals and non-critical signals. The critical signals will be slightly **shorter in duration** than the non-critical signals. Your job will be to press the red button on the subject response pad with your preferred hand immediately after you see a critical signal. If you do not see a critical signal, then do not press the red button on the subject response pad. Do not sacrifice accuracy for speed. A horizontal bar will be continuously presented so you will be required to continuously monitor for the presentation of critical signals. You will have an opportunity to practice the task. Before the experiment begins, you will carry out a training session to ensure you understand the task. You will be given at most two (2) attempts to meet this criterion. If you do not meet the preset criterion in the training session then you will be replaced in the study.

Task #2

You will complete a series of questionnaires.

Benefits of the Study

You will have the opportunity to experience a task that simulates a real-world monitoring task. The results from this study will help increase our understanding of various methods to sustain performance in visual and auditory monitoring tasks. This may lead to improvements in the operational effectiveness of Canadian Forces' UAV operating crew.

Risks

This is a minimal risk study. During the session, you may experience normal levels of eye strain and muscular discomfort from sitting for a prolonged period gazing at the computer monitor. The level of the sound is well below the maximum permissible exposure as set out by the Canada Labour Code. The vibrotactile signals presented on your waist result in very low peak accelerations that are orders of magnitude below the suggested limits for human exposure (as described in standards and directives such as EU 2002/44/EC). *Any questions?*

List of symbols/abbreviations/acronyms/initialisms

ANOVA	Analysis of Variance
CF	Canadian Forces
CPU	Centre Processor Unit
dB	Decibel
dBA	Decibel, ‘A’ weighted
DRDC	Defence Research & Development Canada
DSSQ	Dundee Stress State Questionnaire
HREC	Human Research Ethics Committee
ISR	Intelligence, Surveillance and Reconnaissance
JUSTAS	Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System
LCD	Liquid Crystal Display
MALE	Medium-Altitude, Long-Endurance
Ms	Millisecond
NASA-TLX	National Aeronautics and Space Administration - Task Load Index
ROC	Receiver Operating Characteristic
SD	Standard Deviation
SPL	Sound Pressure Level
UAV	Uninhabited Aerial Vehicle