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Sustained Attention in Auditory and Visual Monitoring Tasks: Evaluation of the Administration of a Rest Break or Exogenous Vibrotactile Signals

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Objective: Performance and mental workload were observed for the administration of a rest break or exogenous vibrotactile signals in auditory and visual monitoring tasks.

Background: Sustained attention is mentally demanding. Techniques are required to improve observer performance in vigilance tasks.

Method: Participants (N = 150) monitored an auditory or a visual display for changes in signal duration in a 40-min watch. During the watch, participants were administered a rest break or exogenous vibrotactile signals.

Results: Detection accuracy was significantly greater in the auditory than in the visual modality. A short rest break restored detection accuracy in both sensory modalities following deterioration in performance. Participants experienced significantly lower mental workload when monitoring auditory than visual signals, and a rest break significantly reduced mental workload in both sensory modalities. Exogenous vibrotactile signals had no beneficial effects on performance, or mental workload.

Conclusion: A rest break can restore performance in auditory and visual vigilance tasks. Although sensory differences in vigilance tasks have been studied, this study is the initial effort to investigate the effects of a rest break countermeasure in both auditory and visual vigilance tasks, and it is also the initial effort to explore the effects of the intervention of a rest break on the perceived mental workload of auditory and visual vigilance tasks. Further research is warranted to determine exact characteristics of effective exogenous vibrotactile signals in vigilance tasks.

Application: Potential applications of this research include procedures for decreasing the temporal decline in observer performance and the high mental workload imposed by vigilance tasks.

Keywords: vigilance, performance efficiency, workload

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INTRODUCTION

Vigilance, also termed *sustained attention*, refers to the ability of observers to maintain attention and remain alert to stimuli for prolonged periods of time (Davies & Parasuraman, 1982; Warm, 1984). Work environments that require sustained attention include detecting targets in military surveillance devices, screening X-rayed carry-on luggage, conducting industrial product control, inspecting anesthesia gauges during surgery, and monitoring automated systems (Warm, Parasuraman, & Matthews, 2008). The failure of operators to sustain attention in these settings could increase the probability that critical signals (e.g., enemy targets and system malfunctions) will not be detected or increase the time taken to respond to critical signals, which could have severe consequences.

The detection of critical signals in monitoring tasks is remarkably fragile. The fragile nature of observer performance is reflected in the decrement function, a decline in the frequency of the detection of critical signals and/or a slower response time to critical signals that are correctly detected. This decline is often complete within the first 30 min of the watch (Davies & Parasuraman, 1982; Warm, 1984), but it can appear within the first 5 min of the watch when the task is highly demanding (Helton et al., 2007; Jerison, 1963; Nuechterlein, Parasuraman, & Jiang, 1983; Rose, Murphy, Byard, & Nikzad, 2002; Temple et al., 2000).

The decline in observer performance is attributed to the high mental workload for processing of information in a vigilance task, and the decrement reflects the depletion of information-processing resources over time (Helton et al., 2005; Johnson & Proctor, 2004; Warm et al., 2008; Warm & Dember, 1998; Warm, Dember, & Hancock, 1996). Additional support that the vigilance decrement

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reflects the temporal depletion of information-processing resources is provided by a decline in cerebral blood flow velocity (CBFV) as measured by transcranial Doppler sonography, a psychophysiological index of information processing resource utilization during sustained attention (Matthews et al., 2010; Shaw et al., 2009; Warm & Parasuraman, 2007). Given the ubiquitous role of vigilance in work environments, techniques to attenuate the vigilance decrement and to reduce the mental workload in vigilance tasks are required to minimize its negative impact on worker health and productivity (Nickerson, 1992).

Techniques to improve observer performance in vigilance tasks have been studied extensively (Davies & Parasuraman, 1982; Warm, 1984; Warm et al., 1996). It is noteworthy that these studies were limited to visual monitoring tasks (Warm et al., 1996). The sensory modality of signals is not a matter of indifference where vigilance is concerned. Monitoring tasks are also performed in the auditory modality. The detection of signals tends to be greater for auditory than for visual vigilance tasks, and the vigilance decrement is less pronounced in the auditory than in the visual modality (Davies & Parasuraman, 1982; Szalma et al., 2004; Warm, Finomore, Vidulich, & Funke, 2015; Warm & Jerison, 1984). The superiority of the auditory modality has been attributed to the decoupling nature of visual displays (Hatfield & Loeb, 1968). Auditory tasks are "closely coupled" because observers in those tasks are usually linked to a source of stimulation, either through headphones or through an enveloping sound field. Hence, the physical orientation of the observer does not affect his or her receptiveness of the stimuli. Visual tasks, on the other hand, are "loosely coupled" because observers are typically free to make head and eye movements, which can be incompatible with viewing the display. Hence, the physical orientation of the observer affects his or her receptiveness of the stimuli.

Those studies that compared auditory and visual monitoring performance did not assess countermeasures for decreasing the mental demand imposed by vigilance tasks (Galinsky, Rosa, Warm, & Dember, 1993; Hatfield & Loeb, 1968; Szalma et al., 2004). Improving observer performance in auditory monitoring tasks is also required given the role that sound plays in everyday life (Kramer, 1994). Workload is also sensitive to the effects of sustained attention in auditory and visual vigilance tasks (Szalma et al., 2004). Accordingly, there is a need to understand whether auditory vigilance tasks also exhibit an increase in observer performance from countermeasures as do their visual analogs or if the tightly coupled auditory modality is less susceptible to such countermeasures given the evidence for superior performance in auditory compared to visual vigilance tasks. One goal for the present study was to examine a rest break for decreasing the decline in observer performance and mental workload in auditory and visual monitoring tasks.

The provision of a rest break during a period of continuous monitoring is an effective countermeasure for restoring performance. N. Mackworth (1950) recommended that the break should occur during the first 30 min of the watch. Breaks from sustained activity as short as 1 min have been shown to restore performance in a visual vigilance task (Ross, Russell, & Helton, 2014) as well as longer breaks introduced in visual vigilance tasks (Colquhoun, 1959; McCormack, 1958; Pigeau, Angus, O'Neill, & Mack, 1995; Zuercher, 1965). We are unaware of studies that assessed the benefits of a rest break for auditory vigilance tasks. Assessing the benefits of a rest break would prove useful for improving observer performance for monitoring auditory signals in operational settings where the auditory modality is superior to the visual modality for the detection of transient signals, such as monitoring operating room alarms (Ferris & Sarter, 2011) and sonar signals (Colquhoun, 1975). For example, transient sonar signals, such as hull popping (e.g., caused by a submarine changing depth) and engine startup sequences, are difficult to disguise in spite of manufacturers' constructing quieter submarines, and thus their detection can serve an important role in alerting the operator to the presence of a potential threatening situation. The provision of scheduled rest breaks in sonar watchstanding (the length of watch can vary between 8 and 12 hr) might help restore operator performance.

Despite the benefits of a rest break, it is not always possible for work–rest schedules in

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operational settings. Other techniques have been utilized to moderate the decline in observer performance that include music (Fox, 1975), odor (McBride, Johnson, Merullo, & Bartow, 2004; Warm, Dember, & Parasuraman, 1991), and caffeine (Temple et al., 2000). Although these techniques have shown promise in sustaining attention, they have limitations in work environments. Music can be distracting and can impair working memory (Baddeley, 1990), certain odors may be prohibited due to a scent-free policy in the workplace, and stimulant drugs can produce harmful side effects (Smith, Gupta, & Gupta, 2007). Given these limitations, we appealed to the tactile sense as a source of exogenous stimulation for the maintenance of sustained attention. The tactile sense can be advantageous because vibrotactile signals can be perceived simultaneously with auditory and visual signals, and the tactile channel is not heavily used. Tactile stimuli were successful as alerting cues to specific forthcoming events (Ferris & Sarter, 2011; Ho, Reed, & Spence, 2007; Hopp, Smith, Clegg, & Heggestad, 2005; Sklar & Sarter, 1999). Exogenous vibrotactile signals have not been used extensively in past vigilance studies. A second goal in our study was to examine the tactile sense as a source of exogenous stimulation for the maintenance of sustained attention and for decreasing the mental workload in auditory and visual monitoring tasks.

The use of exogenous stimulation for the maintenance of observer alertness was suggested by Hebb's (1955) arousal theory. During the vigilance task, loss in performance efficiency could be related to reduction in stimulus variation and thus in arousal level as the task progresses. The introduction of exogenous stimulation would serve to restore an optimal arousal level. Exogenous stimulation has been used to augment performance efficiency in vigilance studies that include music in a visual vigilance task or visual stimulation in an auditory vigilance task (Davenport, 1972; McGrath, 1963). McBride et al. (2004) used vibrations from a pager attached on a belt worn on the waist that yielded shorter latency for target detection in a 3-hr simulated sentry duty task. However, the vibrotactile signals did not enhance target detection, possibly due to the use of only one source of stimulation. Using only one source of stimulation could have contributed to habituation, which is a critical element in the vigilance decrement (Frankmann & Adams, 1962; J. Mackworth, 1969). If the purported alerting properties of tactile stimuli can operate as exogenous stimulation for the maintenance of sustained attention in different sensory modalities, the introduction of exogenous vibrotactile signals might decrease the decline in the detection of critical signals and/or reduce the mental workload imposed by vigilance tasks.

In this study we evaluated the administration of a rest break for restoring performance and vibrotactile signals as a source of exogenous stimulation for the maintenance of sustained attention. The two countermeasures were assessed separately in a 40-min vigilance task that was adapted from Szalma et al. (2004). Participants monitored an auditory or a visual display for changes in signal duration. The efficacy of a rest break and vibrotactile signals were examined for both sensory modalities in comparison with a control condition. For each countermeasure, we measured performance efficiency and workload. If these countermeasures can operate for both sensory modalities, system designers have another vehicle for reducing the workload that accompanies vigilance performance.

We hypothesized that a rest break following the first 30 min of the watch should restore performance efficiency in the last 10 min of the watch for both the auditory and visual modalities. Given that short rest breaks can restore performance efficiency in the visual modality (Colquhoun, 1959; McCormack, 1958; Pigeau et al., 1995; Ross et al., 2014), we would expect that a break should also restore performance efficiency in the auditory modality. In accordance with the arousal model (Hebb, 1955), vibrotactile signals as exogenous stimulation during the 40-min watch should sustain observer performance efficiency in each sensory modality compared to the control condition. Thus, we expect that multiple sources of vibrotactile stimulation should sustain observer performance efficiency and thereby explain the results found by McBride et al. (2004). For each countermeasure, superiority of the auditory modality should be demonstrated by increased performance

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efficiency and decreased mental demand imposed by vigilance tasks.

METHOD

Participants

Ninety-two males and 58 females voluntarily served as participants. They were recruited from the University of Waterloo and were financially compensated. The ages of the males ranged from 17 to 43 years (M = 21.8), and the ages of the females ranged from 17 to 35 years (M = 21.1). Participants self-reported normal hearing and normal or corrected-to-normal vision. None of the participants previously served in vigilance experiments. The study was approved by Defence Research and Development Canada Human Research Ethics Committee and University of Waterloo Office of Research Ethics.

Stimuli

The discrimination of critical signals was based on differences in signal duration, as temporal discrimination is a common dimension in auditory and visual modalities. The auditory signals were bursts of white noise presented binaurally over an AKG 501 headset (Vienna, Austria); neutral events (i.e., stimuli requiring no overt observer response) were 247.5 ms and critical signals were 200 ms. The visual signals were flashes of horizontal white bars measuring 2 mm × 9 mm centered against a gray background on a Philips 220BW 22-in. monitor; neutral events were 247.5 ms and critical signals were 125 ms. The luminance of the horizontal bar was 15.8 cd/m^2 and that of the gray background was 0.3 cd/m^2. The durations of the neutral events and critical signals in this study are identical to those used by Galinsky et al. (1993) and Szalma et al. (2004) and were based on pilot studies using two-alternative forced-choice procedures to equate signal discrimination under alerted conditions.

Experimental Design

Two sensory modalities (auditory and visual) were combined factorially with three countermeasure conditions (rest break, vibrotactile signals, and control that denotes no countermeasure). Twenty-five participants were randomly assigned to each of the six experimental conditions resulting from the factorial combination of sensory modality and countermeasure. Each condition had four 10-min periods of watch.

Apparatus and Measurement: Performance

The experiment was conducted in a quiet room measuring 2.95 m × 3.12 m. Ambient illumination in the test room was 16.6 cd/m^2 and was furnished by overhead florescent lights housed in a parabolic reflector located behind the seated observer. The ambient sound level in the test room was 40.1 dBA. Ambient illumination and sound levels were measured at the start of each experimental session and were extremely consistent throughout the course of the study.

For each sensory modality, stimuli were presented at a rate of 40 per minute by setting stimulus onset asynchrony at 1.5 s; the event rate in this study was identical to that used by Szalma et al. (2004). Each period of watch had 10 critical signals (signal probability = .025). Participants responded to critical signals by pressing the red button on a Cedrus response pad (San Pedro, CA) attached to a Lenovo Intel Core 2 CPU computer. The computer orchestrated stimulus presentations and recorded participants' responses. Responses were recorded as correct detections if the red button was pressed within 1.5 s from the time of onset of the critical signal. All other responses were recorded as false alarms.

The vibrotactile signals were generated using eight C-2 tactors (Engineering Acoustics, Casselberry, FL) embedded in an elastic belt. A vibrotactile pattern consisted of the simultaneous operation of four C-2 tactors that outputted 250 Hz sinusoidal signals for 200 ms. We used 16 distinct vibrotactile patterns (see Figure 1) in order to help avoid habituation (Frankmann & Adams, 1962; J. Mackworth, 1969). A pilot study showed that there was no significant difference in rating annoyance of the 16 vibrotactile patterns (p = .606).

Apparatus and Measurement: Perceived Mental Workload

The NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) is a reliable multidimensional instrument for assessing perceived

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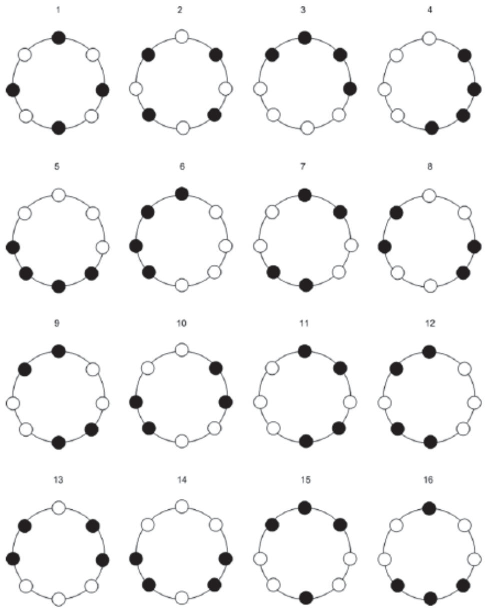

Figure 1. Vibrotactile patterns presented on participant's abdomen. Navel represented by 12 o'clock position and spine represented by 6 o'clock position. Solid shading denotes active tactors.

mental workload of sustained attention (Wickens, Hollands, Banbury, & Parasuraman, 2013). It provides a measure of overall or global workload on a scale from 0 to 100 and also identifies the relative contributions of six sources of workload. Three of these sources reflect the demands that tasks place upon operators (Mental, Physical, and Temporal Demand), while the remaining three sources characterize the interaction between the operator and the task (Performance, Effort, and Frustration). Global workload scores in vigilance typically fall in the middle to upper range of the scale, with Mental Demand and Frustration scales reflecting the principal workload components (Warm et al., 1996).

Procedure

Participants were tested individually. Prior to arriving at the laboratory, participants were requested to wear a cotton T-shirt in order to standardize the application of the tactors to the skin. All participants complied with this request. Upon reporting to the laboratory, participants signed an informed consent form; surrendered their wristwatches, pagers, and cell phones; and had no knowledge of the duration of the experimental session other than it would not exceed 40 min. Subsequently, the experimenter asked to measure the abdomen of the participants so that the tactor belt could be custom fitted. After taking this measurement, the experimenter fitted the tactor belt over the lower margin of the rib cage of the participants with the reference point approximately 35 mm above the navel.

Once fitted with the tactor belt, participants were seated in front of the computer monitor at a viewing distance of approximately 65 cm. A test pattern confirmed that all eight tactors were functional and that participants could readily perceive the vibrotactile signals. Participants were informed that vibrotactile signals may be presented throughout the study. The belt was also worn by participants assigned to the control and rest break conditions in order to control for the effects of wearing the belt for the duration of the watch but was non-operative in these conditions. Similarly, all participants, including those assigned to the visual task, donned the headset in order to control for the effects of wearing headphones for the duration of the watch. For each participant, the apparent loudness of the white noise was matched to the apparent brightness of the visual horizontal bar by a cross-modality matching procedure (Gescheider, 1997).

Prior to commencing the watch, participants completed a 5-min practice session in the assigned sensory modality. All participants were required to detect a minimum of 80% of the critical signals and to commit no more than 10% false alarms. Participants failing to meet these criteria were provided a second practice session; 11 participants could not meet the performance criteria and were replaced.

The 40-min watch commenced immediately once the participants completed the practice session. The watch was divided, without participants' knowledge, into four 10-min periods. Participants received no knowledge of results. Participants in the rest break conditions were given a 5-min break at the completion of the first 30 min of the watch and had no knowledge that a break was forthcoming. During the rest period, participants were allowed to talk or walk about as preferred. Following the break, participants proceeded to perform the monitoring task for 10 min.

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TABLE 1: Mean Percentages of Correct Detections for Each Combination of Sensory Modality, Countermeasure, and Periods of Watch

	Periods of Watch (10 Min)				
Sensory Modality	1	2	3	4	Mean
Auditory					
Ctrl	92.0 (2.0)	82.8 (3.1)	83.2 (3.8)	75.6 (3.9)	83.4 (1.7)
RB	91.6 (2.0)	80.0 (3.9)	84.4 (3.9)	90.0 (2.9)	86.5 (1.7)
VS	82.8 (3.1)	79.2 (3.7)	72.4 (5.3)	69.2 (5.5)	75.9 (2.3)
Mean	88.8 (1.5)	80.7 (2.1)	80.0 (2.6)	78.3 (2.6)	
Visual					
Ctrl	80.0 (3.2)	65.2 (4.2)	55.2 (5.8)	49.6 (6.1)	62.5 (2.7)
RB	84.4 (2.6)	63.6 (4.4)	54.4 (4.7)	64.0 (3.9)	66.6 (2.2)
VS	88.0 (2.3)	70.0 (3.8)	62.4 (5.2)	54.4 (4.4)	68.7 (2.4)
Mean	84.1 (1.6)	66.3 (2.4)	57.3 (3.0)	56.0 (2.9)	

Note. Standard errors in parentheses. Ctrl = control; RB = rest break; VS = vibrotactile signals.

Participants in the vibrotactile signals and control conditions performed the monitoring task for 40 consecutive minutes. However, participants in the vibrotactile signals conditions were administered vibrations from the tactor belt placed on their abdomen during the watch (see Figure 1). Of the 400 events in each period of the watch, there were 280 vibrations (vibration probability = .7). Our criterion for choosing this probability value was based on a pilot study that showed the viability of vibrotactile signals for the maintenance of sustained attention. The vibrotactile patterns in Figure 1 were presented in a random order without replacement. This process was repeated until the vibration probability value in each period was reached. In order to prevent the vibrotactile signals from interfering with the presentation of the auditory and visual stimuli, the vibrotactile pattern was presented 600 ms following signal offset.

At the conclusion of the watch, participants completed a computerized version of the NASA-TLX (Hart & Staveland, 1988). Following the completion of the study, the experimenter debriefed all participants and they were given the opportunity to comment on their monitoring experience.

Data Analysis

For both the detection accuracy data and scores on the NASA-TLX, the mixed linear model was used with compound symmetry to specify the covariance matrix (Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006). The Tukey's honestly significant difference (HSD) test was employed as a post hoc test (alpha value of .05).

RESULTS

Detection Accuracy

The mean percentages of correct detections in all experimental conditions are presented in Table 1. The data were submitted to a 2 (sensory modality: auditory or visual) × 3 (countermeasure: rest break, vibrotactile signals, or control) × 4 (periods of watch: 1, 2, 3, 4) mixed-model analysis of variance (ANOVA), based on an arcsine transformation of the detection accuracy data. There were significant main effects for sensory modality, $F(1, 144) = 40.78$, $p < .001$, $\eta^2 = .15$, and periods of watch, $F(3, 432) = 50.78$, $p < .001$, $\eta^2 = .12$, and a significant interaction between these factors, $F(3, 432) = 10.95$, $p < .001$, $\eta^2 = .03$.

Mean detection accuracy for each sensory modality is plotted as a function of time on task in Figure 2. Although there was a decrement in each sensory modality, it is evident in Figure 2 that the decrement was greater in the visual than in the auditory modality. Post hoc tests showed that detection accuracy was similar between the two sensory modalities in the first 10 min of the watch ($p = .391$), but detection accuracy for each

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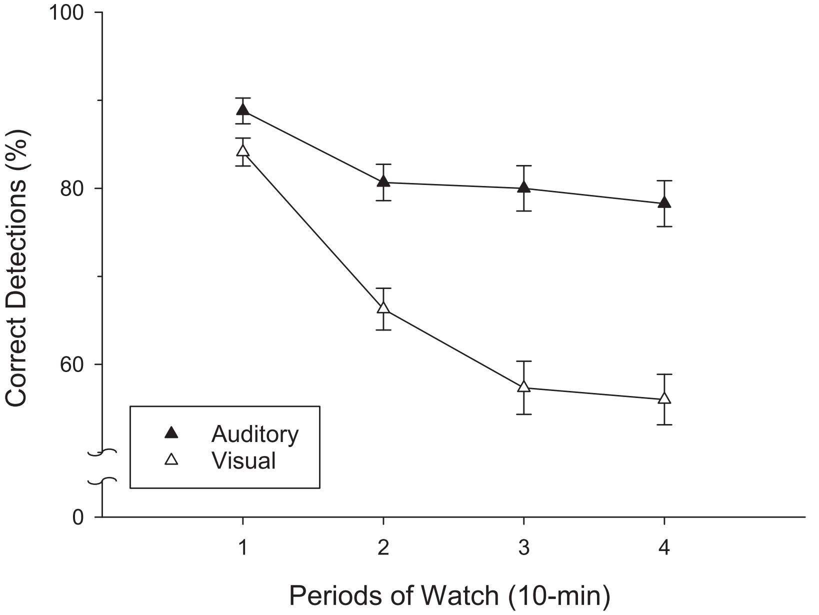

Figure 2. Mean percentages of correct detections for the interaction of sensory modality and periods of watch. Error bars are standard errors.

of the 10-min periods in the remaining 30 min of the watch was superior in the auditory than in the visual modality ($ps < .001$). Moreover, the decline in vigilance performance in the auditory modality was completed within the first 10 min of the watch as demonstrated by the significant difference in detection accuracy between Period 1 and each of the three remaining periods ($ps <$ .001) and the relatively stable performance between each period in the last 30 min of the watch ($ps > .985$). By contrast, the decline in vigilance performance in the visual modality occurred within the first 10 min of the watch (ps < .001) but continued to decline, as mean detection accuracy in Period 2 was significantly greater than that for Period 4 ($p = .02$).

There was no main effect for countermeasure ($p = .273$), but there was a significant interaction between countermeasure and periods of watch, $F(6, 432) = 4.16$, $p < .001$, $\eta^2 = .02$, and a significant interaction between countermeasure and sensory modality, $F(2, 144) = 3.36$, $p = .04$, $\eta^2 = .03$. The significant Countermeasure × Periods of Watch interaction is presented in Figure 3. Performance deteriorated progressively throughout the first 30 min of the watch in spite of exogenous vibrotactile signals and improved after rest. Post hoc tests showed that there were no significant differences in detection accuracy between the three countermeasure conditions within each of the first three periods of the watch ($ps > .376$). However, in Period 4, detection accuracy for the rest break condition (M = 77%) was significantly greater than that for the vibrotactile signals condition (M = 61.8%) and the control condition (M = 62.6%; $ps < .04$), indicating that a short rest break enhanced detection accuracy compared to those participants who had no rest. It should be noted that the break did not restore detection accuracy to its initial level because detection accuracy in Period 4 was significantly smaller than for Period 1 (M = 88%) in the rest condition ($p = .02$).

The significant Countermeasure × Sensory Modality interaction is presented in Figure 4. Post hoc tests showed that detection accuracy for monitoring auditory signals in the rest break (M = 86.5%) and control conditions (M = 83.4%) was significantly greater than that for monitoring visual signals in the rest break (M = 66.6%) and control conditions (M = 62.5%; $ps < .001$). The auditory vibrotactile signals condition (M = 75.9%) and the visual vibrotactile signals condition (M = 68.7%) did not significantly differ in

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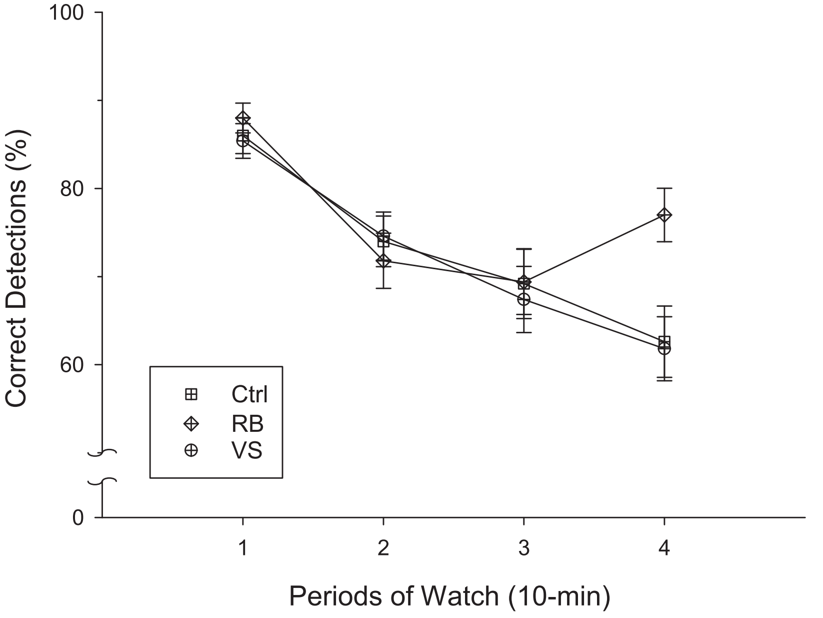

Figure 3. Mean percentages of correct detections for the interaction of countermeasure and periods of watch. Ctrl = control; RB = rest break; VS = vibrotactile signals. Error bars are standard errors.

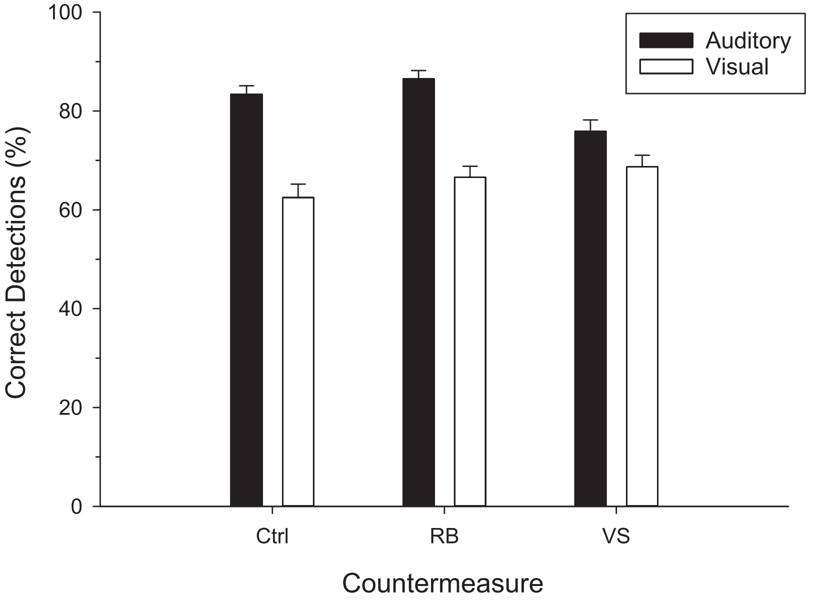

Figure 4. Mean percentages of correct detections for the interaction of countermeasure and sensory modality. Ctrl = control; RB = rest break; VS = vibrotactile signals. Error bars are standard errors.

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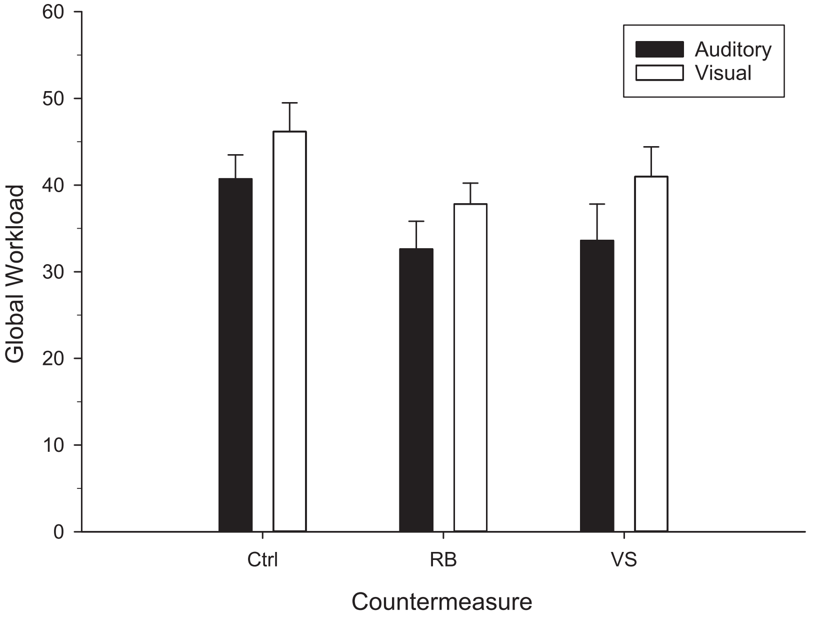

Figure 5. Unweighted mean global workload scores on the NASA Task Load Index for the auditory and visual tasks for each countermeasure. Ctrl = control; RB = rest break; VS = vibrotactile signals. Error bars are standard errors.

detection accuracy ($p = .595$). There was no significant three-way interaction between sensory modality, countermeasure, and periods of watch ($p = .304$).

False Alarms

There were low false alarm rates in this study. The mean percentage of false alarms across all six conditions was 0.8%, with each of the four nonvibrotactile signals conditions having a mean false alarm rate below 1%. The mean false alarm rate for the auditory and visual vibrotactile signals conditions were 1.2% and 1%, respectively. Consequently, false alarm data were not further analyzed.

Workload

Workload scores on the NASA-TLX were calculated for participants in each condition using an unweighted procedure (Nygren, 1991). The mean unweighted global workload scores for the auditory and visual tasks are plotted for the control, rest break, and vibrotactile signals conditions in Figure 5. The unweighted workload scores were submitted to a 2 (sensory modality) × 3 (countermeasure) × 6 (subscale) mixed-model ANOVA. Overall workload was significantly lower in the auditory modality ($M = 35.7$) than in the visual modality ($M = 41.7$), $F(1, 144) = 5.06$, $p = .03$, $\eta^2 = .01$.

There was a significant main effect for countermeasure, $F(2, 144) = 3.43$, $p = .03$, $\eta^2 = .02$. Post hoc tests showed that overall workload in the rest break condition ($M = 35.2$) was significantly lower than the overall workload in the control condition ($M = 43.5$; $p = .03$). There was no significant difference in overall workload between the vibrotactile signals condition ($M = 37.3$) and the control condition and between the vibrotactile signals condition and the rest break condition (*ps* > .147).

There was a significant main effect for subscale, $F(5, 720) = 51.69$, $p < .001$, $\eta^2 = .17$. Post hoc tests showed that the Mental Demand ($M = 47.8$) and Frustration ($M = 50.7$) subscales significantly contributed most to workload, and Physical Demand ($M = 15.6$) significantly contributed least (*ps* < .001). The mean unweighted workload ratings for the Temporal Demand,

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Performance, and Effort subscales were 38.6, 38.7, and 40.6, respectively. None of the interactions were significant (ps > .248).

DISCUSSION

In this study we evaluated whether a rest break or exogenous vibrotactile signals could improve observer performance efficiency in auditory and visual vigilance tasks and decrease the perceived mental workload imposed by vigilance tasks. We attempted to fill the void on the effects of countermeasures with respect to the sensory modality of signals in a sustained attention task, which has been ignored.

Performance Efficiency

Consistent with earlier vigilance studies (Davies & Parasuraman, 1982; Warm, 1984), there was a general decline in detection accuracy between the beginning and the end of 30 min of the watch. There was little difference in detection accuracy between sensory modalities for the first 10 min of the watch, but as time on task increased, detection accuracy in the auditory modality was superior to the visual modality, which is in general agreement with previous findings (Davies & Parasuraman, 1982; Szalma et al., 2004; Warm et al., 2015; Warm & Jerison, 1984).

Rest break. A 5-min rest break was administered after the first 30 min of the 40-min watch. The rest break for participants engaged in either auditory or visual monitoring resulted in improved performance in the last 10 min of the watch compared to those who had no rest. Following the rest break, performance was not restored to its initial level for each sensory modality. This finding can be explained by the relatively short duration of the rest break. In the study by McCormack (1958), there were short and long rest-break conditions. He found that the longer rest resulted in a more beneficial effect. Thus, a longer rest in our study may have restored performance to initial levels for both sensory modalities.

Our results are in general agreement with studies that showed the benefits of a rest for visual vigilance tasks (Colquhoun, 1959; McCormack, 1958; Pigeau et al., 1995; Ross et al., 2014). The present findings extend earlier work by showing that a rest can also enhance performance efficiency in an auditory monitoring task, indicating that the tightly coupled auditory modality also exhibits improved performance efficiency, as does its visual analog. Evidently, the benefits of a rest countermeasure in sustained attention transcend sensory modalities. This finding supports the close linkages between auditory and visual vigilance tasks found in earlier studies (Shaw et al., 2009; Szalma et al., 2004; Warm et al., 2015; Warm & Jerison, 1984).

Various explanations of how a rest break restores performance are possible. According to N. Mackworth's (1950) inhibition theory, the observed improvement in performance following rest is due to participants' being introduced to new stimuli during the break that allowed the original task stimuli to regain novelty. Currently, two dominant theories of vigilance are the resource theory (Warm et al., 2008) and the mindlessness model (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Proponents of resource theory would maintain that the vigilance decrement is accounted through the depletion of information-processing assets that is accompanied by a temporal decline in CBFV. A break would replenish assets as marked by an increase in CBFV and hence result in improved performance. Proponents of the mindlessness model would argue that the repetitive and tedious nature of vigilance tasks is considered to lead observers to withdraw attentional effort from the task and that a break would restore observer attention on the task, resulting in enhanced performance. Yet another model is a new motivational or opportunity cost model (Kurzban, Duckworth, Kable, & Myers, 2013), which posits that declines in performance are a consequence of a trade-off between costs in terms of mental effort and the need to carry out the task. Therefore, observers direct their attentional resources elsewhere. From this perspective, a break would lower the task-induced cost and enhance performance. In essence, there is presently no dominant explanation of how rest breaks operate to restore performance in vigilance tasks.

Vibrotactile signals. Exogenous stimulation in the form of vibrotactile signals was administered throughout the 40-min watch. There was no

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benefit in the maintenance of sustained attention in each sensory modality in spite of varying vibrotactile patterns on the observer's abdomen. McBride et al. (2004) found that exogenous vibrotactile signals had no benefit for target detection in sentry duty, and our study showed that such signals also had no benefit in monitoring auditory or visual signals. The absence of a beneficial effect may have resulted from possible habituation (Frankmann & Adams, 1962; J. Mackworth, 1969). Another explanation could be the absence of varying parameters of the exogenous vibrotactile signals during the watch. We chose to keep constant the tactile parameters in order to maintain experimental control over our independent variable. It is possible that the impact of exogenous vibrotactile signals on sustained attention depends on the characteristics of the vibrating source(s). Indeed, the interactive effects of a stimulus and vigilance can be complex (e.g., see Koelega & Brinkman, 1986, for a review of noise and vigilance). It is noteworthy that early work using exogenous vibrotactile signals yielded shorter target detection latency in sentry duty (McBride et al., 2004). These data indicate that the relationship between exogenous vibrotactile signals and vigilance is not well understood and warrants further exploration.

Workload

The mental workload imposed by the monitoring task in this study was substantial as measured by the NASA-TLX (Hart & Staveland, 1988). The major components of workload were mental demand (Mental Demand subscale) and frustration (Frustration subscale); similar findings were reported in other vigilance studies (Szalma et al., 2004; Temple et al., 2000; Warm et al., 1996, 2008). The difficulty of vigilance tasks can be influenced by various psychophysical factors that include event rate, spatial uncertainty, and noise (Warm et al., 1996), signal salience (Temple et al., 2000; Warm et al., 1996), and also time on task (Szalma et al., 2004). We found that sensory modality of signals is another factor responsible for the workload of sustained attention, with lower perceived mental workload in the auditory than in the visual modality.

The long task duration required participants to maintain a relatively fixed posture for the visual display that can lead to discomfort and restlessness as well as to eyestrain and tension. Indeed, Galinsky et al. (1993) found that fatigue symptoms and restlessness increase considerably over a 50-min watch. Efforts to work under such aversive conditions while continually monitoring displays for critical signals could have resulted in an elevated level of workload for visual monitoring compared to auditory monitoring, although Szalma et al. (2004) did not find such an effect. We presently have no explanation for the differences in workload between the two studies.

In addition to mental workload being sensitive to sensory modality of signals, participants who rested following 30 min of monitoring had lower overall workload than the participants who did not rest (i.e., vibrotactile signals and control conditions). Continuously monitoring displays could have resulted in elevated overall workload. The rested participants resumed the monitoring task for 10 min and then reported the workload of the task. Consequently, perceived mental workload following a rest would be expected to be lower compared to monitoring for 40 consecutive minutes. This finding suggests that rest break is another factor responsible for the workload of sustained attention. To our knowledge, Ross et al. (2014) was the first to show that a rest break can reduce the perceived workload of a visual vigilance task as measured by the NASA-TLX (Hart & Staveland, 1988). Our study confirmed that finding and also showed that a short rest break reduced the workload of an auditory vigilance task as well. Mental workload was not sensitive to exogenous vibrotactile signals.

CONCLUSIONS AND IMPLICATIONS

This study was prompted by the requirement to propose techniques for enhancing the quality of monitoring in vigilance tasks that are mentally demanding (Warm et al., 2008). The results of this study indicate that a short rest break can restore detection accuracy in the auditory and visual modalities. The implication of our finding is that a short rest break enhances performance in both sensory modalities, but neither sensory modality had performance restored to its initial levels. Previous studies have not shown the

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benefits of a rest break on observer performance for auditory vigilance tasks. Moreover, a rest break can reduce the associated mental workload of vigilance tasks independent of the sensory modality of signals. Exogenous vibrotactile signals did not restore an optimal arousal level.

This study can be generalized for real-world applications. First, the provision of scheduled rest breaks from sustained activity, even as short as 1 min (Ross et al., 2014), should be carefully considered in work environments whenever possible to help reduce the negative impact on worker health and productivity (Nickerson, 1992). Second, system designers need to capitalize on the strength of the sensory modality of signals. The auditory modality is superior to the visual modality for the detection of transient signals, such as monitoring operating room alarms (Ferris & Sarter, 2011) and sonar signals (Colquhoun, 1975). Additionally, we showed that auditory vigilance tasks are less mentally demanding than their visual counterparts. Third, a rest break improved detection accuracy in not only a visual monitoring task but also an auditory monitoring task. Taken together, this paper addressed techniques for counteracting the vigilance decrement for real-world applications, which is a key issue in vigilance research. Although sensory differences in vigilance tasks have been studied (e.g., Galinsky et al., 1993; Hatfield & Loeb, 1968; Szalma et al., 2004), this study is the initial effort to investigate the effects of a rest break countermeasure in auditory and visual vigilance tasks, and it is also the initial effort to explore the effects of the intervention of a rest break on the perceived mental workload of auditory and visual vigilance tasks. These results are intended to aid operator performance in vigilance tasks.

Aiding operator performance is crucial in real-world applications given the increased role of automation in everyday life. Automation has altered the role of operators from active controllers to passive monitors of displays, intervening only in the event of imminent problems (Sheridan, 1987). However, automation may decrease situation awareness arising from vigilance and complacency problems (Endsley & Kiris, 1995). A human–machine system needs to be designed to know when to aid the operator by means of countermeasures, which should be timed and/or varied to counteract the peaks of decline in observer performance during the watch. This design would require a noninvasive and inexpensive neuroimaging tool (e.g., transcranial Doppler sonography) to "monitor the monitor" and to help decide when operator vigilance has reached a point where task aiding is necessary or operators need to be given rest breaks or removed (Warm & Parasuraman, 2007).

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KEY POINTS

- Participants monitored an auditory or a visual display for changes in signal duration in a 40-min watch. During the watch, participants were administered a rest break or vibrotactile signals as a source of exogenous stimulation.
- Detection accuracy was significantly greater in the auditory than in the visual modality.
- A short rest break significantly enhanced detection accuracy in each sensory modality more than for participants who did not rest.
- Participants had significantly lower perceived mental workload for monitoring auditory signals than for monitoring visual signals.
- A rest break resulted in significantly lower mental workload in both sensory modalities.
- Exogenous vibrotactile signals had no beneficial effects on performance or mental workload.

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