British Journal of Psychology (2005), 96, 249–261

The British Psychological Society
www.bpsjournals.co.uk

Signal regularity and the mindlessness model of vigilance

William S. Helton[1]*, Todd D. Hollander[2], Joel S. Warm[2], Gerald Matthews[2], William N. Dember[2], Matthew Wallaart[2], Gerald Beauchamp[2], Raja Parasuraman[3] and Peter A. Hancock[4]

[1]Michigan Technological University, USA
[2]University of Cincinnati, USA
[3]George Mason University, USA
[4]University of Central Florida, USA

Robertson, Manly, Andrade, Baddeley, and Yiend (1997) have proposed that detection failures in vigilance tasks result from a 'mindless' withdrawal of attentional effort from the monitoring assignment. To explore that view, they modified the traditional vigilance task, in which observers make button-press responses to signify the detection of rarely occurring critical signals, to one in which button-press responses acknowledge frequently occurring non-signal events and response withholding signifies signal detection. This modification is designed to promote a mindless withdrawal of attentional effort from the task through routinization. The present study challenges the validity of the mindlessness model by showing that with both types of task, observers utilize subtle patterns in the temporal structure of critical signal appearances to develop expectations about the time course of those appearances that affect performance efficiency. Such expectations enhance performance on the traditional vigilance task, but degrade performance on the modified task.

Vigilance or sustained attention tasks typically require observers to monitor displays over extended periods, and to execute overt detection responses to the appearance of low probability critical signals. The signals are usually clearly perceivable when observers are alerted to them but are not compelling changes in the observers' operating environment. In addition, the signals are usually embedded in a context of recurrent non-signal (neutral) events, which, unlike signals, require no overt response from observers (Davies & Parasuraman, 1982; Warm, 1984; Warm & Jerison, 1984). Vigilance tasks and the processes that influence their performance are of interest because of the insights they provide into the factors that control attention (Broadbent,

*Correspondence should be addressed to Dr William Helton, Department of Psychology, Michigan Technological University, Houghton, MI 499312, USA (e-mail: deak_helton@yahoo.com).

DOI:10.1348/000712605X38369

1971). They are also of interests given the vital role that vigilance plays in automated human-machine systems in transportation, process and quality control, medicine, and, of special interest here, baggage inspection at airport security checkpoints (Hancock & Hart, 2002; Wickens & Hollands, 2000).

In a recent series of studies, Robertson and his colleagues (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson *et al.*, 1997) have argued that detection failures in vigilance tasks are due to gross inattention or 'mindlessness' on the part of observers. According to this perspective, when observers are confronted with the need to respond to infrequent signals separated by long intervals, as in the case of vigilance, a supervisory attentional system (Norman & Shallice, 1986; Shallice, 1988; Stuss, Shallice, Alexander, & Piction, 1995) loses its potency and observers cease to focus their awareness on the task concerned. Instead, they approach their assignment in a thoughtless, routinized manner, characterized by the withdrawal of effortful attention from the task. This approach reflects an endogenous modulation of attention rather than the decline in wakefulness and vigour accompanying lowered arousal (Dickman, 2002).

Based upon their conception, Robertson and his associates introduced a modification to the standard vigilance paradigm designed to more rapidly elicit this mindless state. Observers are required to respond overtly to non-signals and to withhold overt responses to signals. Presumably, detection failures in the modified vigil can be attributed to routinization, automaticity, and lapses of attentional focus, all features of 'mindlessness' (Laberge, 1995; Langer, 1989) generated by uniform, repetitive responding to more numerous non-signal events. The research of Robertson and colleagues supports the general role of mindlessness in vigilance based on their finding using the modified task that absent-minded individuals, defined by high scores on the Cognitive Failures Questionnaire (CFQ; Broadbent, Cooper, Fitzgerald, & Parkes, 1982), do more poorly on this task than those who have low scores on the CFQ.

However, the model proposed by Robertson and his associates has been challenged by a number of studies that indicate that, although tedious, vigilance tasks impose a substantial mental burden upon observers, as reflected in elevated scores on the NASA Task Load Index (NASA-TLX), an instrument which provides a reliable measure of the perceived mental workload incurred in performing a task (Hart & Staveland, 1988; Wickens & Hollands, 2000). The workload scores for vigilance are greater than those typically obtained in several other types of tasks, including time estimation, grammatical reasoning, and simple tracking, and the workload of sustained attention has been shown to be rooted in the information-processing demands of the vigilance task itself, rather than being a consequence of combating the boredom associated with the task (Hitchcock, Dember, Warm, Moroney, & See, 1999; Warm, Dember, & Hancock, 1996). Moreover, contrary to expectations derived from the mindlessness model, absent-minded individuals (those with high CFQ scores) perform as well on a traditional vigilance task as non-absent-minded individuals (those with low scores on the CFQ) but rate the task as more mentally demanding on the NASA-TLX than do non-absent-minded individuals (Grubb *et al.*, 1994). Such results are more consistent with the notion that performance failures in vigilance are a consequence of a depletion in information-processing resources rather than from a thoughtless approach to the task (Davies & Parasuraman, 1982; Matthews, Davies, Westerman, & Stammers, 2000; Warm & Dember, 1998).

In addition to imposing a substantial workload upon individuals, vigilance tasks can also be highly stressful, as reflected in observers' self-reports of negative mood shifts after participating in a vigil (Hancock & Warm, 1989; Helton, Dember, Warm, & Matthews, 1999; Szalma *et al.*, 2004; Temple *et al.*, 2000; Warm, 1993). Given current transactional models of stress, in which stress is viewed as arising from individuals' appraisal of their environment as taxing or exceeding their coping resources (Kemeny, 2003; Matthews, 2001), these results are also consistent with the view that detection failures in vigilance reflect limitations in effortful attention rather than mindlessness. Of particular importance to the Robertson model is a recent report by Grier *et al.* (2003) indicating that a high workload/high stress profile typifies observers' reactions to the Robertson group's modified vigilance task as well as to the more traditional vigilance tasks. In that study, workload was measured by the NASA-TLX while task-induced stress was measured via the Task engagement and distress scales of the Dundee Stress State Questionnaire (DSSQ; Matthews *et al.,* 1999), a well-validated instrument for assessing transient states associated with mood, arousal, and fatigue (Matthews *et al.*, 2002). The DSSQ is designed to reflect the affective, motivational, and cognitive aspects of stress via three factor-analytically derived scales, Task engagement, Distress, and Worry. Task engagement contrasts enthusiasm and interest with fatigue and apathy. The Distress factor reflects tension, feelings of unhappiness, and low confidence, while the Worry factor encompasses cognitive interference arising from task-related and personal concerns, low self-esteem, and self-focus of attention.

Although subjective reports of high workload and stress provide evidence against the role of mindlessness in the standard vigilance paradigm and also in the Robertson modification, they do so indirectly by measuring the cognitive and emotional consequences of the information-processing load imposed by the task. Consequently, although the subjective reports of observers in both the standard and modified vigilance tasks indicate that the observers found the tasks to be difficult, this result does not necessarily exclude mindlessness from playing a role in their performance. It is conceivable that mindlessness could have been the consequence of an avoidance or coping strategy designed to reduce exposure to the cognitive and emotional demands of the task (Matthews & Wells, 1996). This line of argument led us to seek a more direct test of the mindlessness issue, particularly concerning the Robertson modification, by focusing upon the performance aspect of the observer's information-processing activities.

As described by Coren, Ward, and Enns (2004), observers in attention-demanding situations have the ability to actively utilize past experience to form expectancies about anticipated stimulus events and prepare for their occurrence by aligning attention with their anticipated time of arrival. This effect is exemplified in the standard vigilance paradigm by the signal regularity effect, wherein signal detectability is enhanced when the temporal intervals between critical signals for detection occur in a regular and predictable fashion as opposed to an irregular and unpredictable one (Hollander *et al.*, 2003; Warm, Dember, Murphy, & Dittmar, 1992; Warm & Jerison, 1984). The ability of observers to be responsive to signal predictability provides evidence against a gross 'mindless' approach to the standard vigilance task. One might argue that like the subjective report data described above, the signal regularity effect does not necessarily refute the role of mindlessness in vigilance because learning studies have shown that contextual regularities that affect performance can be acquired independent of awareness (Chun & Jiang, 1998). However, as Baars (2002) has indicated, observers in these studies must consciously attend to the target stimuli in order to make use of such regularities. Hence, any evidence indicating the influence of signal regularity on observers' performance suggests active attention to the target stimuli, or 'mindfulness', not mindlessness. Accordingly, we tested the mindlessness model by looking at the effects of signal regularity on the modified vigilance task. The model leads to the prediction of reduced or no effects of signal regularity in the modified task. On the other hand, observation of such effects would provide converging evidence (cf. Kramer, Coles, & Logan, 1996) against the model in general, and the notion that mindlessness plays a key role in the modified task in particular. The latter issue is important given that the modified task has begun to attract experimental interest as a vehicle for studying attentional lapses broadly defined (Smallwood *et al.*, 2004).

Method

Participants

Participants were 80 University of Cincinnati undergraduates (40 women and 40 men) who took part in this study to satisfy a course requirement. Their ages ranged from 18 to 28 years ($M = 19.23$, $SD = 1.32$). All the observers had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. Twenty observers (10 male and 10 female) were assigned at random to each of four conditions resulting from the factorial combination of task type (standard and modified) and regularity (regular signal schedule and irregular signal schedule).

Apparatus

All observers participated in a 40-minute vigil divided into four continuous 10-minute periods. They inspected the repetitive presentation on a video display terminal (VDT) of a simulated air traffic control display described by Hitchcock *et al.* (1999, 2003) and were tested individually in a 1.95 × 1.90 × 1.88 m industrial acoustics sound chamber. The VDT was situated on a table approximately 66 cm from the seated observer. Ambient illumination in the chamber (4.46 cd/m^2) was provided by a 25-watt bulb housed in a parabolic reflector and mounted above and behind the monitor to preclude glare on the VDT.

As illustrated in Fig. 1, the display comprised a 'city' (a solid red circle, 10.5 mm in diameter, luminance = 23.7 cd/m^2) banded by a thin white border

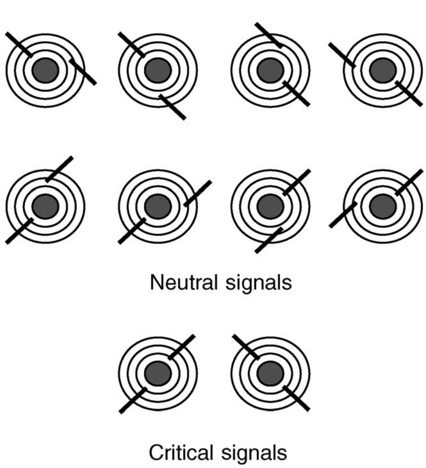

Figure 1. The simulated air traffic control display showing all possible neutral (safe) and critical (emergency) events.

(0.75 mm thick × 12 mm in diameter) ringed by three circular white 'outer markers' (0.75 mm thick; 28, 53, and 83 mm in diameter, respectively; luminance = 79.2 cd/m^2) and two 'jet aircraft' (represented by two 1 × 25 mm grey lines), all of which were presented on a light grey background (luminance = 29.6 cd/m^2).

In all conditions, the display was updated 30 times per minute with an exposure time of 300 msec. The Michaelson contrast ratio ([maximum luminance – minimum luminance/maximum luminance + minimum luminance] × 100; Coren *et al.*, 2004) of the aircraft to their background was 2%. The low contrast ratio was used to reduce signal salience because the signal regularity effect is more likely to be observed with low than with high salience signals (Davies & Tune, 1969; Hollander *et al.*, 2003). The aircrafts were equidistant from the city (each reached the innermost marker), approaching it from opposite headings, either from north-west to south-east or north-east to south-west. Critical signals for detection (emergency events) were cases in which the two aircraft were aligned on a collision path over the centre of the city. Neutral events (safe events) were one of eight permutations of the non-collision flight heading. In all experimental conditions, 20 critical signals were presented in each10-minute period of watch. In the regular signal condition, inter-signal intervals were fixed at one critical signal every 30 seconds; in the irregular signal condition, inter-signal intervals ranged from 12 to 60 seconds, with a mean of 30 seconds. Stimulus presentations and response recording were orchestrated by a Macintosh personal computer.

Procedure

Observers in the standard condition responded to critical signals by pressing a key on a response pad, while making no overt response to neutral signals. In the modified condition, these instructions were reversed; observers pressed a key in response to neutral events and withheld overt responding to critical signals.

Prior to the initiation of the main vigil, observers in both the standard and modified conditions had a 10-minute practice session with computer-controlled feedback, in which a male voice informed the observer of correct detections (hits) and detection failures (misses) based upon the type of response (key press or the lack thereof) appropriate for the condition in which they participated. The experimenter ensured that observers in the standard condition clearly understood that a key press unaccompanied by verbal feedback constituted an inappropriate rejection or false alarm. Likewise, those in the modified group understood that withholding of a key press unaccompanied by verbal feedback constituted a false alarm. Feedback was not available during the main vigil. To be retained in the study, observers were required to have a minimum of 75% correct detections with no more than 10% false alarms during the practice session. All observers met this dual criterion. Observers surrendered their watches and cell phones upon entering the testing chamber and had no knowledge of the length of the vigil other than it would not exceed 90 minutes.

All observers completed a pre-task version of the DSSQ prior to the initiation of the practice phase of the experimental session and a post-task version of the mood scale containing a shortened adaptation of the NASA-TLX immediately upon completing the main vigilance task (Matthews *et al.*, 2002). The modified NASA-TLX omits the paired comparison procedure of the standard version, an omission that is not deemed critical for valid workload assessment with this instrument (Nygren, 1991). Omission of the paired comparison procedure allowed the NASA-TLX to be embedded conveniently within the DSSQ and avoided the necessity of running separate groups of participants with each scale to control for the possibility of inter-scale interactions. These measures permitted replication of Grier *et al.*'s (2003) earlier finding that the modified vigil parallels the workload and stress responses associated with the standard vigil.

Results

Correct detections

In the standard vigil, correct detections were defined as key presses to the occurrence of critical signals (emergency events) on the air traffic control display. In the modified vigil, correct detections were defined as the withholding of key presses to such signals. The percentages of correct detections in all experimental conditions were subjected to a 2 (task) × 2 (regularity) × 4 (periods of watch) mixed ANOVA (ANOVA) in which the arcsine transformation was used to normalize the data (Kirk, 1995). The analysis revealed that the overall detection rate in the standard vigil ($M = 81.93\%$, $SE = 1.9$) was significantly higher than that in the modified vigil ($M = 73.78\%$, $SE = 3.0$), $F(1, 76) = 5.83$, $p < .05$, $\varepsilon^2 = .07$, and that the overall level of signal detections declined significantly over time: *M*s for Periods 1–4 were 85.3% ($SE = 1.7$), 78.9% ($SE = 2.0$), 77.3% ($SE = 2.4$), and 69.7% ($SE = 2.5$), respectively, $F(2.9, 217.9) = 19.36$, $p < .001$, $\varepsilon^2 = .20$. Moreover, there was a significant task × regularity interaction, $F(1, 76) = 12.85$ $p < .001$, $\varepsilon^2 = .15$. None of the remaining sources of variance in the analysis was significant, $p > .05$ in each case. In this and in subsequent analyses, Box's epsilon was used when appropriate to compute degrees of freedom for the repeated measures factors to correct for violations of the sphericity assumption (Maxwell & Delaney, 2004).

The task × regularity interaction is shown in Fig. 2 (error bars are standard errors). In the standard vigil, the percentage of correct detections was higher for regular ($M = 86.95\%$, $SE = 2.3$) than for irregular ($M = 76.91\%$, $SE = 2.6$) signals, while the level of signal detections in the modified vigil was higher for irregular ($M = 80.09\%$, $SE = 4.0$) than for regular ($M = 67.48\%$, $SE = 4.1$) signals. The regular/irregular signal difference was statistically significant with both types of vigilance tasks, modified:

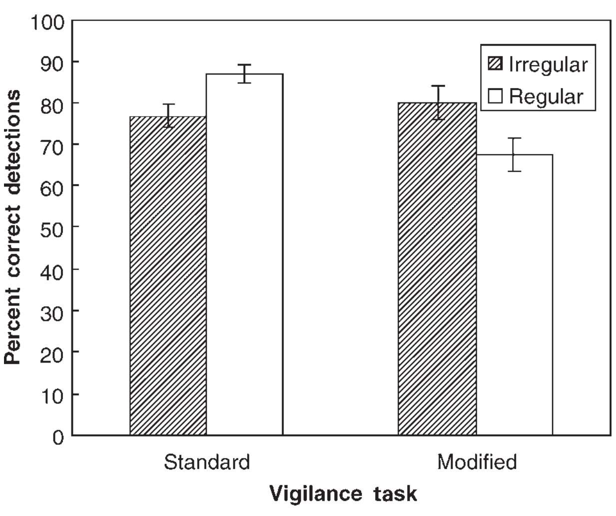

Figure 2. Mean percentages of correct detection for the standard and modified vigilance tasks under the regular and irregular signal conditions (error bars are standard errors).

$t_{(two-tail)}(38) = 2.36$, $p < .025$, $d = .77$; standard: $t_{(two-tail)}(38) = 2.88$, $p < .025$, $d = .94$.

False alarms

In the standard vigil, false alarms were defined as key presses to the occurrence of neutral events (safe events) on the air traffic control display. In the modified vigil, false alarms were defined as the *withholding of key presses* to such events. A 2 (task) × 2 (regularity) × 4 (periods of watch) mixed ANOVA based upon an arcsine transformation of the false alarm percentages revealed that false alarms were significantly greater when signals appeared on a temporally irregular ($M = 5.85\%$, $SE = 0.7$) as compared with a regular ($M = 3.73\%$, $SE = 0.6$) schedule, $F(1, 76) = 6.41$, $p < .01$, $\varepsilon^2 = .08$, and that the overall level of false alarms increased over time, $F(2.3, 175.8) = 4.87$, $p < .01$, $\varepsilon^2 = .06$. Moreover, this increase over time was dependent upon task, $F(2.3, 175.8) = 4.07$, $p < .01$, $\varepsilon^2 = .05$. None of the other sources of variance in the analysis was significant, $p > .05$ in each case. The task × periods interaction is shown in Fig. 3 (error bars are standard errors). It is evident that while the false alarms rates in the two tasks were similar initially, the rate of gain in false alarms over time was greater in the modified than in the standard vigil.

Workload and stress

As with the original version of the NASA-TLX (Hart & Staveland, 1988), mean global workload scores on the shortened adaptation of the TLX used in this study could range from 0 to 100. Mean global workload scores for the standard-regular, standard-irregular,

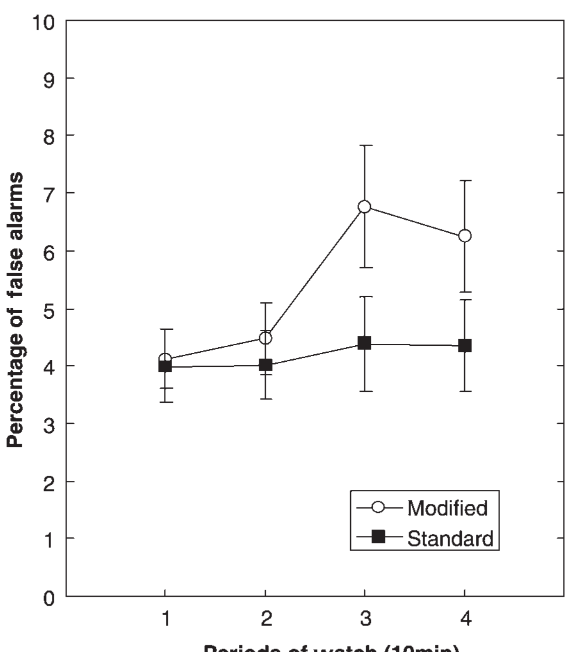

Figure 3. Mean percentages of false alarms for the standard and modified vigilance tasks as a function of periods of watch (error bars are standard errors).

modified-regular, and modified-irregular conditions were 54.2 (95% CI = 47.9–60.5), 53.7 (95% CI = 47.4–60.0), 50.3 (95% CI = 44.0–56.6), and 55.1 (95% CI = 48.9–61.4), respectively. All of these mean values fell above the mid-point of the scale. A 2 (task) × 2 (regularity) ANOVA of the ratings revealed that similarly high levels of workload were found in all conditions of the study, $p > .05$ for all sources of variance in the analysis. Uniformity of workload in regard to the standard and modified versions of the vigilance task is consistent with the report by Grier and her associates (2003).

Factor score estimates for the DSSQ Task engagement, Distress, and Worry scales were calculated using standardized regression weights from a large normative sample, as outlined by Matthews *et al.* (2002). Distributions of sample factor scores may be compared to the mean of 0 and *SD* of 1 in the normative sample. Following the procedure adopted in previous vigilance studies with the DSSQ (Grier *et al.*, 2003; Helton, Warm, Matthews, Corcoran, & Dember, 2002; Temple *et al.*, 2000), change scores based on the DSSQ norms for the three factors were determined for each participant using the formula normalized post-task factor score – normalized pre-task factor score. A 2 (task) × 2 (regularity) × 3 (factor) ANOVA of the change scores revealed there were no significant differences between any of the conditions, $p < .05$. The overall mean change scores for Task engagement, Distress, and Worry were -1.02 (95% CI = -1.18– -0.85), 1.09 (95% CI = 0.91–1.27), and -0.36 (95% CI = -0.53– -0.19), respectively. For all experimental conditions, the confidence intervals excluded 0, indicating that all three factors were significantly different after the experimental session than they were prior to its start.

Discussion

Consistent with prior findings based on the traditional vigilance paradigm (Hollander *et al.*, 2003; Warm *et al.*, 1992; Warm & Jerison, 1984), observers in the standard format detected critical signals (i.e. appropriately pressed the response key to emergency events) more frequently and made fewer false alarms (i.e. appropriately refrained from pressing to safe or neutral events) when critical signals appeared on a temporally regular as compared with a temporally irregular schedule. As noted at the outset of this paper, the study by Baars (2002) indicates that for signal regularity to facilitate performance in this way, observers need to be processing the temporal structure of signal occurrences. Hence, they could not be inattentive or mindless during the task.

Signal regularity had an impact on performance in the modified format as well, albeit in a different manner. The presence of a main effect for signal regularity in the analysis of the false alarm scores and the absence of a concomitant task × regularity interaction in those scores implies that as in the case with the standard vigil, signal regularity also lowered the false-alarm rate in the modified vigil, as reflected in this case in a reduction of inappropriate withholding of the key-press response to safe events. However, contrary to the finding with the standard vigil, the significant task × regularity interaction in the correct detection data of the modified vigil indicated that regularity also lowered the detection rate of critical signals in the modified vigilance paradigm, as reflected in a reduction of appropriate withholding of the key-press response to critical signals. The fact that signal regularity affected performance efficiency at all in the modified vigil renders suspect the mindlessness hypothesis because it implies that observers in the modified vigil, like those in the standard vigil, were indeed processing the temporal structure of signal appearances during the watch.

The finding that signal regularity lowered critical signal detections in the modified vigilance task is unusual, but it is not unprecedented. An earlier study by Scerbo, Warm, and Fisk (1986) found a reversal of the signal regularity effect when the periodicity of critical signal appearances conflicted with the periodicity of the schedule of neutral background events in which the critical signals were embedded (event asynchrony). A different sort of conflict – that between a supervisory attentional-control system and a task-induced motor routine – is probably the source of the reversal in the present study.

Observers in the modified vigil were confronted with a situation in which they were to make key presses to a frequently occurring imperative stimulus signifying safe events on the air traffic control display and to make the 'response of not responding' when the imperative stimulus occasionally indicated an emergency event. As described by Doyon, Prenhune, and Ungerleider (2003), the need for repetitive key pressing to safe or neutral events in the modified vigil is the sort of task requirement that leads to the development of a feed-forward motor scheme. Evidence indicates that feed-forward motor routines and attention rely on separate neural systems (Gazzaniga, Ivry, & Mangun, 2002; Harrington & Haaland, 1991; Hellige, 1993; Tucker & Williamson, 1984). However, the present study, where a strong habitual response (key pressing) needed to be overcome when critical signals appeared, the feed-forward motor routine built up by the continual pressing in the modified task would require modulation by a supervisory attentional control system (Logan & Cowan, 1984; Matthews *et al.*, 2000; Norman & Shallice, 1986; Shalice, 1988; Stuss *et al.*, 1995) to determine when response withholding was necessary. As Reason (1984) has indicated, well-rehearsed motor routines can conflict with the supervisory activities of an attentional-control system. In the present case, such conflict could be rooted in the need for the attentional control system to maintain expectancy in active memory, a burden that may have diverted resources away from maintaining control of the motor response. Thus, in the modified-regular condition, the motor response system would have had more opportunity to act independently of the attentional control system, rendering observers in that condition less able than those in the irregular signal condition to execute the proper response-withholding action in the presence of critical signals. The lower false-alarm rate with regular signals in the modified task can also be accounted for on the basis of motor responses' bypassing an attentional control system, since a reduction of false alarms in the modified task implies an increase in the emission of the key-pressing response to neutral events. In essence, it appears that the consequence of expectancy formation in the modified vigil was to reduce the control of motor behaviour and observers' ability to withhold a motor act.

As in the earlier experiment by Grier *et al.* (2003), observers' false-alarm rates in the modified task were generally higher than those of observers in the standard task late in the session. Thus, observers in the former condition improperly withheld key pressing to safe or neutral events more frequently than those in the standard vigil improperly executed key presses to those events as the vigil wore on. A possible explanation for this result is muscle fatigue; the frequent pressing of the response key could have induced muscle tiredness and led observers in the modified condition to hold back the required motor response to neutral events. That possibility seems unlikely, since, as was the case in the earlier study, post-experimental interviews did not elicit complaints of tiredness, muscle pain, or finger discomfort from observers in the modified vigil. Additionally, if fatigue was a factor, then the 'hit' rate in the modified vigil, reflected in response withholding to critical signals, should have increased over time, but instead it decreased. As Sanders (1998) has indicated, a major function of the supervisory attentional system in motor programming is to monitor optimal performance. Since observers in vigilance experiments can secure implicit feedback about performance efficiency with continued exposure to the task (Loeb & Binford, 1964; Warm, Kanfer, Kuwada, & Clark, 1972), it is conceivable that those in the modified vigil were aware of their inability to suppress overt responding to critical signals as the vigil wore on, and this response conflict meant that they were increasingly hesitant to execute the key-press response in the presence of the more frequent safe events. Evidently, the Robertson modification of the standard vigilance paradigm has the potential for eliciting conflict at different levels of perceptual-motor activity, with local effects linked to the expected time of appearance of critical signals and global effects based on performance over time. Viewed in this way, the dynamics of the modified vigil are more complex than envisioned by Robertson and his associates and transcend the routinized mindlessness depicted in their model of vigilance performance.

In addition to challenging the mindlessness model of vigilance through measurements of performance, the results of this study confirm and extend Grier *et al.*'s (2003) findings concerning the cognitive and emotional consequences associated with task performance. As Grier and her associates noted, findings such as these also challenge the picture of vigilance failures as being a consequence of mental quiescence. In this study, observers in both the standard and modified task conditions found their vigilance assignment to impose a high level of workload. Both tasks were also stressful in that distress increased and task engagement declined during the watch, a pattern typical of a variety of vigilance tasks (e.g. Matthews *et al.*, 2002). The state of fatigue indicated by loss of task engagement was accompanied by the negative emotions and cognitions of loss of control that define the distress state. Consistent with other work on fatigue (Matthews *et al.*, 2000), the observer performing a vigilance task is not in a passive, mindless state, but is attempting to cope actively with a state of growing emotional and cognitive disturbance. Indeed, high workload appears to be one of the main drivers of distress in performance settings (Matthews *et al.*, 2002). It should also be noted that, although scores on the Worry scale declined during the vigil, reduction of worry is typical of task performance in general, as the task imperative refocuses attention from personal concerns to task-processing (Matthews *et al.*, 2002). The overall decline seen here (-0.36 *SD*s) is smaller than that seen for other tasks that are not believed to be mindless, such as visual working memory (-0.8 *SD*s), auditory working memory (-0.8 *SD*s), and reading magazines (-0.9 *SD*s; Matthews *et al.*, 2002). Therefore, the level of worry in the present study was somewhat greater than that in those other tasks. Indeed, Grier *et al.*, found that one of the core components of worry – cognitive interference resulting from thoughts about the task – actually increased during the vigil. Thus, the patterned stress state seen in vigilant observers, regardless of task version, is inconsistent with an approach to vigilance that characterizes mental operations as increasingly routine, automatic, and passive.

In sum, the results of the present study challenge the assertion by Robertson and his colleagues (Manly *et al.*, 1999; Robertson *et al.*, 1997) that detection failures in vigilance tasks can be accounted for in terms of mindlessness on the part of observers. In both the standard and modified conditions of this study, observers were sensitive to subtle regularities in the temporal structure of critical appearances, a result indicating active attention to the vigilance display, and they also reported feelings of distress and high mental workload. Rather than an account anchored in mindlessness, wherein observers are viewed as treating the task in a routinized, automated manner, both of these findings support an information-processing account of vigilance in which observers are considered to be actively attending to a resource-demanding task (Davies & Parasuraman, 1982; Matthews *et al.*, 2000; Warm & Dember, 1998). Moreover, the present results indicate that rather than promoting mindlessness, Robertson *et al.*'s modification of the traditional vigilance task – respond overtly to frequent non-signals and withhold overt responding to infrequent signals rather than the other way around – serves an opposite function. It complicates the observer's chore by adding a motor-control dimension to the traditional perceptual task of separating signals from noise.

Acknowledgements

Supported by the Department of Defense's Multidisciplinary University Research Initiative (MURI) program administered by the Army Research Office under grant DAAD19-01-1-0621 to Dr. P.A. Hancock, principal investigator. The views expressed in this work are those of the authors and do not necessarily reflect Army policy. We thank Drs. Mike Drillings, Elmer Schmeisser, and Sherry Tove for providing administrative and technical direction for the grant.

References

Baars, B. J. (2002). The conscious access hypothesis: Origins and recent evidence. *Trends in Cognitive Sciences*, *6*, 47–52.

Broadbent, D. E. (1971). *Decision and stress*. New York: Academic Press.

Broadbent, D. E., Cooper, P., Fitzgerald, P., & Parks, K. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology*, *21*, 1–16.

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology*, *36*, 28–71.

Coren, S., Ward, L. M., & Enns, J. T. (2004). *Sensation and perception* (6th ed.). Hoboken, NJ: Wiley.

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

Davies, D. R., & Tune, G. S. (1969). *Human vigilance performance*. New York: American Elsevier.

Dickman, S. J. (2002). Dimensions of arousal: Wakefulness and vigor. *Human Factors*, *44*, 429–442.

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

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2002). *Cognitive neuroscience: The biology of the mind* (2nd ed.). New York: Norton.

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

Grubb, P. L., Miller, L. C., Nelson, W. T., Warm, J. S., Dember, W. N., & Davies, D. R. (1994). Cognitive failure and perceived workload in vigilance performance. In M. Mouloua & R. Parasuraman (Eds.), *Human performance in automated systems: Current research and trends* (pp. 115–121). Hillsdale, NJ: Erlbaum.

Haarington, D. L., & Haaland, K. Y. (1991). Hemispheric specialization for motor sequencing: Abnormalities in levels of programming. *Neuropsychologia*, *29*, 147–163.

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

Hancock, P. A., & Warm, J. S. (1989). A dynamic model of stress and sustained attention. *Human Factors*, *31*, 519–537.

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: North-Holland.

Hellige, J. B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA: Harvard University Press.

Helton, W. S., Dember, W. N., Warm, J. S., & Matthews, G. (1999). Optimism, pessimism, and false failure feedback: Effects on vigilance performance. *Current Psychology*, *18*, 311–325.

Helton, W. S., Warm, J. S., Matthews, G., Corcoran, K., & Dember, W. N. (2002). Effects of signal salience and jet aircraft engine noise on performance and stress in an abbreviated vigilance task. *Proceedings of the Human Factors and Ergonomics Society*, *46*, 1546–1551.

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

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

Hollander, T. D., Warm, J. S, Matthews, G., Dember, W. N., Tripp, L. D., & Parasuraman, R. (November, 2003). *Cerebral hemovelocity and the signal regularity effect in vigilance*. Paper presented at the meeting of the Psychonomic Society, Vancouver, British Columbia.

Kemeny, M. E. (2003). The psychobiology of stress. *Current Directions in Psychological Science*, *12*, 124–129.

Kirk, R. E. (1995). *Experimental design: Procedures for the behavioral sciences* (3rd ed.). Pacific Grove, CA: Brooks/Cole.

Kramer, A. F., Coles, M. G. H., & Logan, G. D. (Eds.), (1996). *Converging operations in the study of visual selective attention*. Washington, DC: American Psychological Association.

LaBerge, D. (1995). *Attentional processing: The brain's art of mindfulness*. Cambridge: Harvard University Press.

Langer, E. J. (1989). *Mindfulness*. Reading, MA: Addison-Wesley.

Loeb, M., & Binford, J. R. (1964). Vigilance for auditory intensity changes as a function of preliminary feedback and confidence level. *Human Factors*, *7*, 445–458.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*, 295–327.

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

Matthews, G. (2001). Levels of transaction: A cognitive science framework for operator stress. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload, and fatigue* (pp. 5–33). Mahwah, NJ: Erlbaum.

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

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

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

Matthews, G., & Wells, A. (1996). Attentional processes, coping strategies and clinical intervention. In M. Zeidner & N. S. Endler (Eds.), *Handbook of coping: Theory, research, applications* (pp. 573–601). New York: Wiley.

Maxwell, S. E., & Delaney, H. D. (2004). *Designing experiments and analyzing data: A model comparison perspective* (2nd ed.). Mahwah, NJ: Erlbaum.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research*, Vol. 4 (pp. 1–17). New York: Plenum.

Nygren, T. E. (1991). Psychometric properties of subjective workload measurement techniques: Implications for their use in the assessment of perceived mental workload. *Human Factors*, *33*, 17–33.

Reason, J. (1984). Lapses in attention in everyday life. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 515–549). Orlando, FL: Academic Press.

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.

Sanders, A. F. (1998). *Elements of human performance: Reaction processes and attention in human skill*. Mahwah, NJ: Erlbaum.

Scerbo, M. W., Warm, J. S., & Fisk, A. D. (1986). Event asynchrony and signal regularity in sustained attention. *Current Psychological Research and Reviews*, *5*, 335–343.

Shallice, T. (1988). *From neuropsychology to mental structure*. Cambridge, UK: Cambridge University Press.

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

Stuss, D. T., Shallice, T., Alexander, M. P., & Picton, T. W. (1995). A multidisciplinary approach to anterior attentional functions. *Annals of the New York Academy of Sciences*, *769*, 191–209.

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

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

Tucker, D. M., & Williamson, P. A. (1984). Asymmetric neural control systems in human self-regulation. *Psychological Review*, *91*, 185–215.

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

Warm, J. S. (1993). Vigilance and target detection. In B. M. Huey & C. D. Wickens (Eds.), *Workload transition: Implications for individual and team performance* (pp. 139–170). Washington, DC: National Academy Press.

Warm, J. S., & Dember, W. N. (1998). Tests of a vigilance taxonomy. In R. R Hoffman, M. F. Sherrick, & J. S. Warm (Eds.), *Viewing psychology as a whole: The integrative science of William N. Dember* (pp. 87–112). Washington, DC: American Psychological Association.

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and applications* (pp. 183–200). Mahwah, NJ: Prentice-Hall.

Warm, J. S., Dember, W. N., Murphy, A. Z., & Dittmar, M. L. (1992). Sensing and decision-making components of the signal-regularity effect in vigilance performance. *Bulletin of the Psychonomic Society*, *30*, 297–300.

Warm, J. S., & Jerison, H. J. (1984). The psychophysics of vigilance. In J. S. Warm (Ed.), *Sustained attention in human performance* (pp. 15–59). Chichester, UK: Wiley.

Warm, J. S., Kanfer, F. H., Kuwada, S., & Clark, J. L. (1972). Motivation and vigilance: Effect of self-evaluation and experimenter controlled feedback. *Journal of Experimental Psychology*, *92*, 123–127.

Wickens, C. D., & Hollands, J. G. (2000). *Engineering psychology and human performance* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Received 20 November 2003; revised version received 1 February 2005