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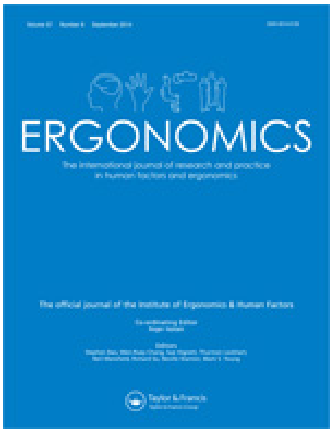

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Vigilance on the move: video game-based measurement of sustained attention

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Vigilance represents the capacity to sustain attention to any environmental source of information over prolonged periods on watch. Most stimuli used in vigilance research over the previous six decades have been relatively simple and often purport to represent important aspects of detection and discrimination tasks in real-world settings. Such displays are most frequently composed of single stimulus presentations in discrete trials against a uniform, often uncluttered background. The present experiment establishes a dynamic, first-person perspective vigilance task in motion using a video-game environment. 'Vigilance on the move' is thus a new paradigm for the study of sustained attention. We conclude that the stress of vigilance extends to the new paradigm, but whether the performance decrement emerges depends upon specific task parameters. The development of the task, the issues to be resolved and the pattern of performance, perceived workload and stress associated with performing such dynamic vigilance are reported.

Practitioner Summary: The present experiment establishes a dynamic, first-person perspective movement-based vigilance task using a video-game environment. 'Vigilance on the move' is thus a new paradigm for the evaluation of sustained attention in operational environments in which individuals move as they monitor their environment. Issues addressed in task development are described.

Keywords: vigilance; sustained attention; video games; monitoring; workload

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Vigilance, the capacity to sustain attention to an artificial display or an environment over prolonged periods on watch, has been extensively investigated now for almost 70 years (Mackworth 1948; see also Hancock 2013). This capacity is an important component of performance in many applied domains, including security (Hancock and Hart 2002; Hancock and Szalma 2003), driving (Mackie and O'Hanlon 1977), aviation (Pigeau Angus, O'Neill, and Mack 1995; Wiggins 2011), medicine (Gill 1996; Meyer and Lavin 2005; Paget, Lambert, and Sridhar 1981), as well as a whole spectrum of military operations (Lieberman, Castellini, and Young 2009). It is critical to note that these are only exemplar domains, and elements of vigilance occur in many if not most aspects of human existence.

The most frequently reported finding in the whole domain of vigilance is that the quality of sustained attention declines with time on watch (See et al. 1995). This 'vigilance decrement' has been observed in both laboratory and field experiments (for a recent review of the latter see Drury, forthcoming, but see also Hancock 2013). The decline in performance is usually accompanied by high levels of perceived workload and stress (Hancock and Warm 1989). Several psychophysical dimensions of the task and other associated factors have been identified that moderate associated performance, workload and stress (for reviews see Davies and Parasuraman 1982; Warm, Dember, and Hancock 1996; Warm and Jerison 1984; Warm, Parasuraman, and Matthews 2008).

For most of the life of vigilance as a formal scientific concern, the stimuli that have been used in typical vigilance studies have consisted of both simple and artificial elements that purport to represent important aspects of detection and discrimination tasks in operational settings (see examples in Figure 1). The genesis of such nominal 'tasks' derived from and date from the original work of Mackworth (1948, 1950) who developed the now famous 'Mackworth Clock Task' (see Figure 1a) to simulate the representative elements of the radar detection task in which empirical reports of the decrement were first observed in an operational setting (for a brief historical review of the origins of vigilance research see Warm 1984, see also Hancock 2013).

Other examples of task stimuli that have been used in vigilance research include detecting different line lengths (Becker, Warm, and Dember 1994), relative lightness of pairs of circles (Warm et al. 2009), differentiating between 'O's, 'D's and backwards 'D's (Helton et al. 2008, 2010; Temple et al. 2000), symbols of aircraft flying in circular patterns (Funke et al. 2010), air traffic control displays which show flight paths represented as lines (Hitchcock et al. 1999; Reinerman-Jones et al. 2011), and discriminations among digit pairs that meet a preset mathematical criterion (Deaton and Parasuraman 1993;

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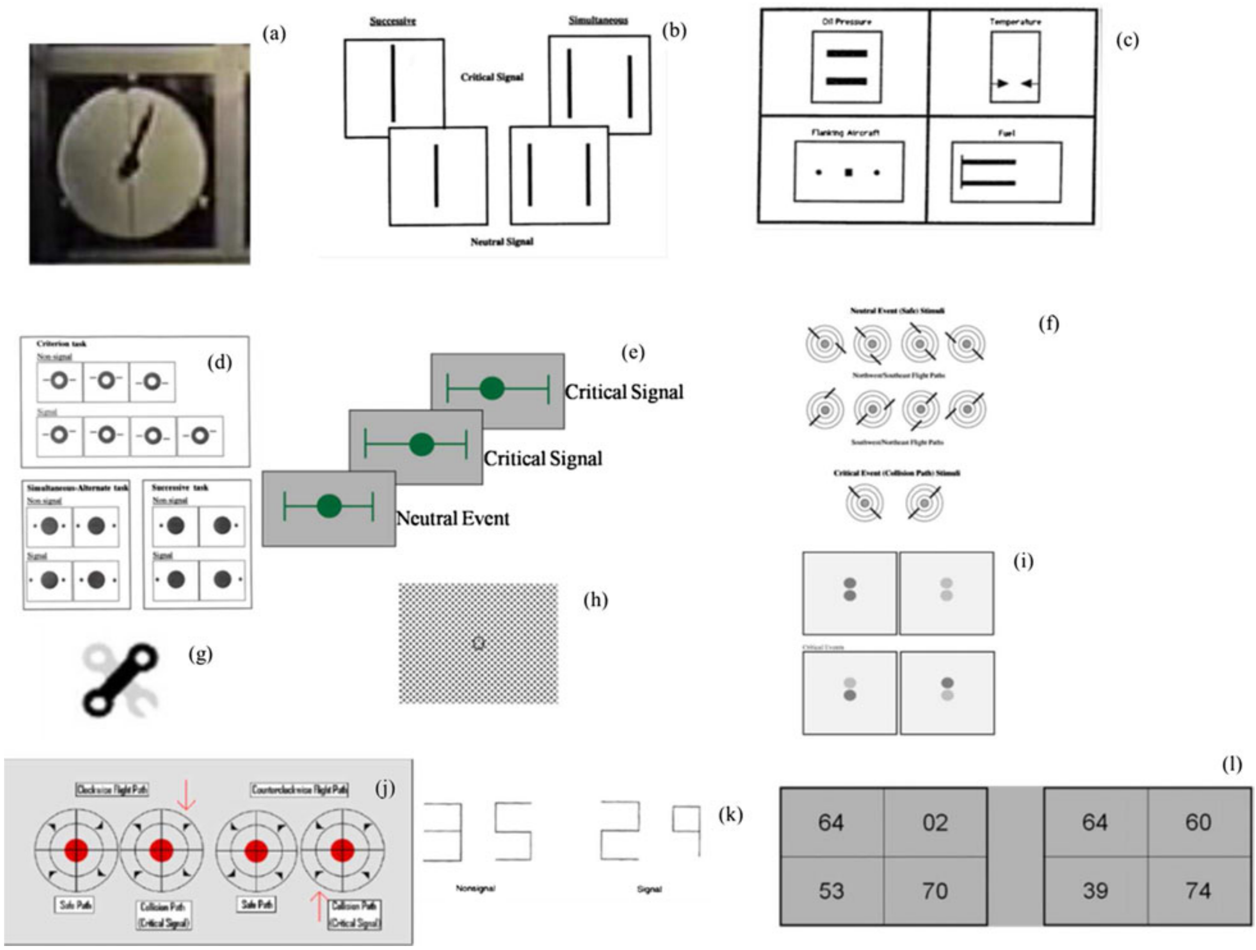

Figure 1. Examples of stimuli used in traditional vigilance research. In each case, the stimuli are presented on discrete trials. Figures adapted from: (a) Mackworth Clock Mackworth (1948, 1950); (b) Becker, Warm, and Dember (1994); (c) Grubb (1995); (d) Szalma (1997); (e) Szalma et al. (2006); (f) Hitchcock et al. (1999); (g) Caggiano and Parasuraman (2004); (h) Temple et al. (2000); (i) Warm et al. (2009); (j) Funke et al. (2010); (k) Deaton and Parasuraman (1993); (l) Szalma and Teo (2012).

Szalma and Teo 2012; Warm et al. 1984). In virtually all of these cases, the stimuli to be inspected were presented in a series of individual discrete trials. Although such configurations can be representative of some actual real-world tasks, they bear only a limited and restricted resemblance to the relevant features of many real-world detection requirements.

The majority of vigilance studies have employed the above referenced static displays that present stimulus events against only a uniform, uncluttered background. These presentations comprise a fixed number of targets embedded in a temporal sequence of a fixed number of non-signal events. The durations of stimulus presentation and the inter-stimulus interval are also carefully controlled in such experimental procedures. Control of these presentation dimensions enables the systematic manipulation of factors such as event rate, temporal uncertainty, inspection time and signal probability, among others (see Warm and Dember 1998; Warm and Jerison 1984). It also serves to facilitate the computation of outcome measures (e.g. proportion of hits, false alarms and signal detection theory measures of sensitivity and response bias).

In contrast to this, most operational settings are dynamic such that the flow of information is continuous rather than discrete. Environments surrounding any pre-specified or spontaneous target comprise a multitude of irrelevant objects rather than a uniform or uncluttered background, and in some circumstances observers also move through the environment as they monitor. One most obvious domain with these latter characteristics is the detection of improvised explosive devices (IEDs) in military operations, in which individuals must move through an environment that they must scan continuously for the potential presence of targets. Soldiers on dismounted patrol or motorised route clearance missions move through environments in which targets are embedded in a whole spectrum of irrelevant stimuli. The target placement is both spatially and temporally uncertain and thus purposefully difficult to predict, while the tactical situation is such that there is only limited time available to inspect any scene for indicators of IEDs (for evaluations of IED detection tasks see Martin and Karthaus 2009; Vaughan et al. 2009).

While traditional vigilance tasks can represent some features of this form of monitoring, they do not capture the dynamic, first-person perspective movement through scenes to be inspected. Therefore, one primary goal of our work here was to extend vigilance beyond its traditional confines into the context of dynamic detection using a video game-based platform. The work reported here was also part of a larger programme of effort to develop a video game-based training module for vigilance (Szalma et al. 2011; Teo et al. 2012). Here, we describe the development of this new experimental paradigm for sustained attention research, and we report the underlying experimental procedure while also identifying the issues in the development of such a task and promising approaches for future advancement.

Extension of the vigilance paradigm using video game-based tasks

The overall purpose for this research was to identify which parameters of a video-game environment may be adjusted to create a monotonous vigilance task. In this respect, the present work summarises efforts to establish this new paradigm by titration of video-game parameters. Also, we sought to establish whether patterns observed in extant vigilance research extended to this task in which first-person perspective movement represents one, if not the key feature. In the present work we therefore developed a task that included many of the representative elements of the vigilance paradigm (i.e. prolonged monitoring requirement, monotony, relatively infrequent targets appearing with high spatial and temporal uncertainty; Hancock 2013; Warm and Jerison 1984), but in which discrete static displays were replaced by continuous first-person perspective movement through a scenario. The primary experimental goal for the present study was to determine whether traditional vigilance extended to a dynamic (i.e. movement-based), first-person perspective video-game environment.

A first concern in establishing this new paradigm was whether it was even feasible to extend the traditional vigilance paradigm to a video-game environment, as the latter is typically designed to be both interesting and engaging: the antithesis of the monotony of vigilance. The initial challenge lay primarily in two properties of video games that are uncharacteristic of typical vigilance: the quantity and density of (mostly irrelevant) stimuli in the task scenario, and the dynamic movement through the task environment presented on the display.

Typical vigilance tasks provide observers with little perceptual stimulation. That is, vigilance tasks generally employ displays that are perceptually impoverished (Hancock 2013). Video games, however, are usually perceptually rich environments. Although there are preliminary suggestions that vigilance decrements can occur with stimuli comprising natural scenes (Head and Helton 2012), we sought to establish a video-game environment that contained representative elements of operational contexts (e.g. buildings, trees and other objects in the scene), but that retained the element of monotony and repetitiveness.

Dynamic stimulus presentation is a second feature of video games that is uncharacteristic of most laboratory-based vigilance tasks. In using discrete stimulus presentations the majority of studies reflect the discrete nature of some vigilance tasks (e.g. Gill 1996; Sheehan and Drury 1971). However, they clearly do not represent the continuous nature of stimulus inspection as, for example, in IED detection. Even cases in which the stimulus display can be considered continuous (e.g. Wilkinson 1961), the continuity comprises a blank display on which signals occasionally appear. That is, there were no discrete presentations of neutral events, but rather the 'stimulus' of a blank screen. There are instances in which movement has been a feature of a vigilance task (e.g. Finomore et al. 2013; Funke et al. 2010; Montague and Webber 1965), but in these cases the displays were either two-dimensional or 'top-down' perspectives (e.g. see Figure 1j).

Establishment of task parameters

The first step in the development of any vigilance task is to determine the stimulus characteristics, particularly the properties of stimuli to be defined as targets. To avoid confounding sustained attention with target discrimination, researchers typically select stimuli that can be detected under alerted conditions on most trials (e.g. 85–90% of trials) using a two-alternative forced choice procedure (2AFC; e.g. Szalma 2011; Szalma et al. 2004). Hence, an initial step in our task development was to determine whether the stimuli to be discriminated in the monitoring task could be detected under alerted conditions; i.e. under conditions in which there is no uncertainty regarding *whether* a target is present during a trial, but the observer must be able to accurately decide *which* of two stimulus events includes a target. The 2AFC procedure is referred to as an 'alerted condition' because on each trial the participant knows a priori that one of the two stimulus presentations will include a target.

For the present work, 2AFC tasks were used to identify a pool of target stimuli for use in a vigilance task (for details see Szalma et al. 2014). The scenarios for the 2AFC and the vigilance studies were created in the Virtual Battlespace 2 (VBS2

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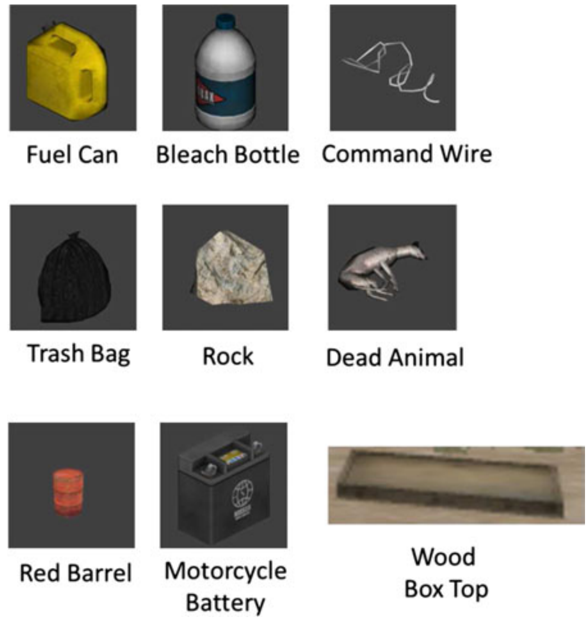

Figure 2. Images of targets (isolated from the scenario context) for the experiment.

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version 1.4) simulation. Several targets were selected from the VBS2 object library that were (1) representative of potential objects currently in operational environments that could serve as IED indicators, (2) easily detectable under alerted conditions (using a criterion of ~90% accuracy) and (3) similar to one another in discriminability. Nine objects commonly encountered in rural Afghan villages were selected as candidate targets: a red barrel, a motorcycle battery, a bleach bottle, a dead animal, a rock, a trash bag, a command wire, a fuel can and a wooden box top (see Figure 2).

The 2AFC studies employed a scenario consisting of trials of two brief video clips that presented a first-person perspective view of the terrain and surrounding objects in the scene. The task required the participants to detect targets placed in one of two 10-s video clips on each trial. Each clip in the pair was identical to the other in every respect with the exception that one clip contained the target while the other did not. Each target was presented on multiple trials, and on each trial the target was placed in different locations within the scenario in order to explore the effects of contextual cues on target detection (see Figure 3). The participant's task was to decide on each trial whether the target was presented in the first or the second video clip, and to respond via a mouse click when prompted to make that decision.

The proportion of participants ($N = 20$) who detected each type of target in each scenario is provided in Table 1 for one of the 2AFC pilot studies (for details see Szalma et al. 2014). There were clear differences in detectability as a function of target type. Across three different 'scenarios' (patterns of placement of both targets and non-target objects), the rock, the red barrel and the bleach bottle were generally very easy to detect, and the command wire proved very difficult to detect, with scores for the latter well below the objective of ~90% detectability. In general, and as expected, this evaluation established that target salience is sensitive to the context within which it is placed in the virtual environment. The pattern of results of the 2AFC experiments indicated that the following factors were most useful in obtaining target configurations that were detectable under alerted conditions:

a. *Target occlusion*: Occlusion of the target can be accomplished using objects such as desert plants, trees, a donkey cart, mud walls, a well, trash heaps and buildings. Targets should emerge from behind objects as the person 'moves' through the scenario. This is necessary to avoid the problems associated with targets emerging slowly from a long distance (from the participant's perspective) as compared to a 'pop-out' effect of targets placed in a scene at closer distances (see also Hancock and Manser 1997). Targets were placed in occluded positions to better control the ease of detection and to limit the duration of target exposure.
b. *Colour/shade matching*: The matching of colours/shades of target to nearby objects (i.e. similarities in colour and lightness of figure and ground) is a useful technique for titrating target salience. For instance, the battery (see Figure 2) blended well (but was detectable by most participants) when placed next to a donkey cart tire (both objects being black; see Figure 5), light brown burlap bags can be mistaken for the yellow container if viewing time is brief and placing the yellow container against light coloured walls rendered it less salient in the scenario (see Figure 5). Similarly, there were grey sacks in some scenarios that were similar in colour and shape to the dead animal.

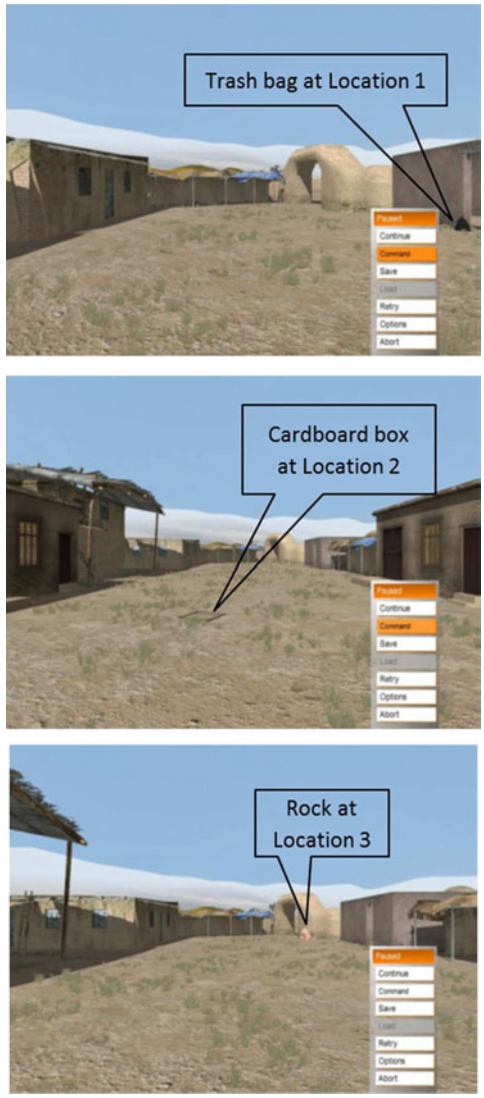

Figure 3. Examples of targets to be detected in a rural village scenario. Note that during the task the target label and the menu in the lower right-hand corner of each image were not present.

Table 1. 2AFC experiment: proportion of participants who detected each target for each scenario ($N = 20$).

Scenario	Target									Mean
	Barrel	Battery	Bottle	Animal	Rock	Bag	Wire	Wood box	Yellow container	
1	1.00	0.80	1.00	1.00	1.00	0.90	0.70	1.00	0.90	0.92
2	0.95	1.00	0.85	1.00	1.00	1.00	0.80	0.90	1.00	0.94
3	0.35	1.00	0.95	1.00	0.95	0.95	0.65	0.55	0.90	0.81
4	0.95	0.90	0.95	0.85	1.00	0.95	0.75	1.00	1.00	0.93
5	1.00	0.90	1.00	0.50	0.85	0.90	0.70	0.60	0.95	0.82
6	0.70	0.65	1.00	0.90	0.90	0.95	0.70	0.75	0.90	0.83
7	0.95	0.65	0.90	0.95	0.90	0.60	0.65	0.70	0.85	0.79
Mean	0.84	0.84	0.95	0.89	0.94	0.89	0.71	0.79	0.93	

Note: The extremely low proportion for the Barrel in Scenario 3 was an artefact resulting from an error in placement of the barrel (it was placed outside of the field of view of the scenario).
Source: Szalma et al. (2014).

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c. *Time on screen*: As would be expected in any detection task, longer durations of target exposure were associated with higher levels of detection by participants. Target duration on the screen should therefore be carefully controlled using occluding objects so that it is not more than a few seconds; this is so particularly for larger targets.
d. *Target placement*: The placement of targets in the periphery versus in the centre of the scene can be controlled by varying the occlusion, movement speed and time on screen.

From these results of the 2AFC studies, target-location pairs were selected that were associated with 90% detection rates. The results also indicated that targets such as the red barrel and command wire should be avoided as these were too easy or difficult, respectively, to detect (regardless of the location at which they were placed). Based on these results, four stimuli were omitted as targets for subsequent investigation. Three stimuli were eliminated because they proved too salient (i.e. the bleach bottle, the rock and the red barrel), and one stimulus (the command wire) was omitted because it was too difficult to detect.

An empirical test of 'vigilance on the move'

Having established these initial premises, the superordinate purpose for the present investigation was to validate a video game-based vigilance task that featured first-person perspective movement through a virtual environment, but also included key characteristics of traditional static vigilance tasks (i.e. prolonged monitoring requirement, monotony, relatively infrequent targets appearing with high spatial and temporal uncertainty; Hancock 2013; Warm and Jerison 1984). As noted previously, the present work was part of a larger programme of effort to develop a video game-based training module for vigilance (Szalma et al. 2011; Teo et al. 2012), and thus the primary experimental goal for the following study was to determine whether traditional vigilance extended to a dynamic, first-person perspective video-game environment.

Experimental method

Participants

Participants were 28 students (12 female) who ranged in age from 17 to 21 years ($M = 18.3$; SD = 1.0).

Experimental design

A one-way within-participants design was used to evaluate changes in performance during practice and test vigils. Perceived workload was measured using the NASA TLX (Hart and Staveland 1988), a self-report measure comprising six scales, three of which assess perceptions of the task (mental, physical and temporal demand) and the other three scales assessing the participant's perception of their response to the task (effort, frustration and perception of one's own performance), and a global index of workload computed from the weighted average of the six scales. Stress was measured using the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 1999, 2002), which is composed of three broad factors of the cognitive, affective and energetic components of stress (task engagement, distress and worry). Coping was measured using the coping inventory for task stress (CITS; Matthews and Campbell 1998), which assesses the degree to which participants use three coping strategies (task-focused, emotion-focused and avoidant coping) during task performance. NASA-TLX and coping scores were analysed via a one-way within-subjects ANOVA for the practice and test vigils. DSSQ (Matthews et al. 2002) scores were analysed via a one-way within-participants ANOVA for the pre-task, post-practice and post-test vigils.

Creation of a vigilance scenario in a video-game environment

The scenario for the vigilance task was created within the Geotypical Afghanistan Terrain of VBS2 (see Figure 4) using the non-target objects identified in the previous study, so that it contained a larger variety of objects for a more diverse environment of irrelevant stimuli.

A path of movement through the village was defined by creating boundaries through the placement of buildings, walls and trees on either side of the waypoints. The areas around the path were populated with civilians and animals as well as a variety of other objects to facilitate target occlusion, e.g. walls, small trash piles, wood pallets by shop entrances, tall desert grass and donkey carts (see Figure 5). Some of the objects placed were similar in colour, shape or size to the targets to be detected. These objects included burlap sacks, wooden pallets and grey sacks that resembled the fuel can, wood box top and the dead animal, respectively.

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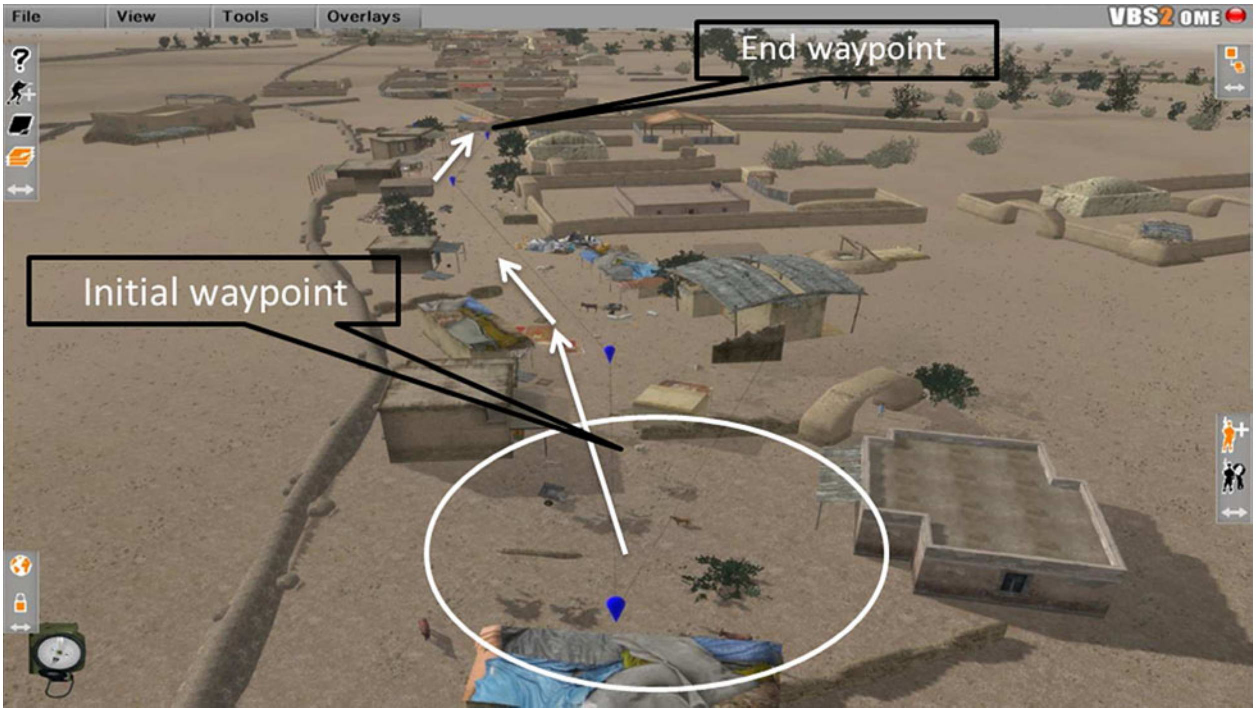

Figure 4. Aerial view of the scenario route for the experiment. Waypoints are depicted as blue teardrop shapes. This is also the view used to build the scenario, as this perspective facilitates more precise placement of objects within the environment. Participants began at a waypoint marked by the white circle. They would move along the waypoints in the direction of the white arrow. The red areas denote the areas from which the system was selecting targets.

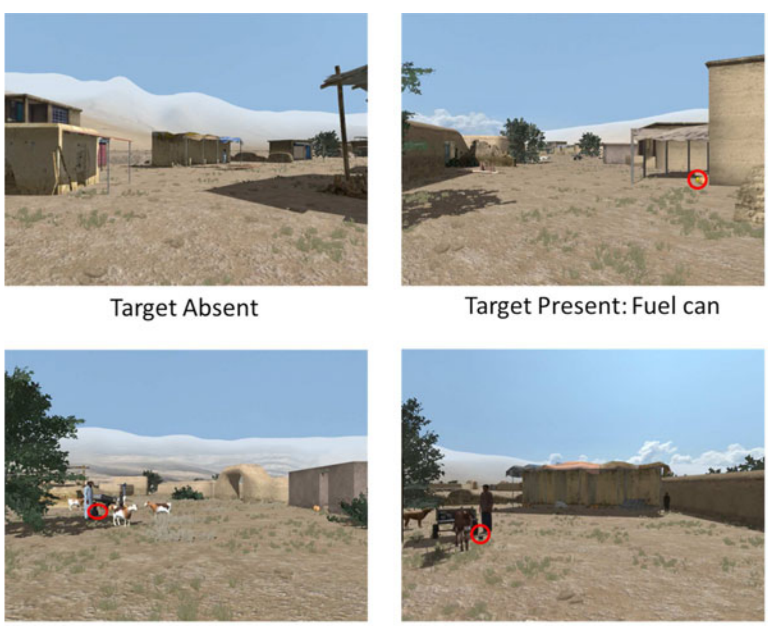

Figure 5. Example scenes used in initial development of the vigilance task. Different scenes were created by replacing the objects in the original scene with different configurations of walls, buildings, trees, etc., and adding novel objects (e.g. donkey cart, trash heap). Targets are circled in red for this illustration. Objects such as the burlap sacks in the open doorway, trees and bushes, and living objects (i.e. Afghan civilians) were placed in this scenes to create a more cluttered environment for target occlusion.

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Target selection and placement

Based on the 2AFC study, five targets were selected for the vigilance task: the fuel can, trash bag, dead animal, motorcycle battery and the wood box top (see Figure 2).

As this task was part of a larger effort to develop a vigilance training module, it was necessary to ensure that the random distribution of target placements was different for each run by the controlling software programme. Several potential targets were therefore placed along the path to increase the pool of targets from which the computer could randomly select for placement at a particular location. This prevented repetitions of target patterns presented to participants, an important feature of tasks that may be administered to operators multiple times in training for vigilance.

At time intervals set by the researcher, the computer searched the environment for an object identified as a potential target to be detected at that location, and it randomly selected that target from the pool of available targets at the specified locations. This target was then made visible in the scene (no other targets defined in the area were displayed). Targets were set to appear at a rate of one target per half minute (1 per 30 seconds). This target rate is similar to that used in traditional vigilance research (i.e. 1–2 signals per minute; Becker, Warm, and Dember 1994; Szalma 2011; Szalma et al. 1999, 2004, 2006).

Vigilance task

The practice and test vigils each required participants to assume the perspective of a Soldier patrolling on foot through a sector of a rural Afghan village. The pace of movement was set at 1.8 m/s for both phases, and was based on initial tests which had indicated that this rate of movement avoided both floor and ceiling effects. Participants repeated the patrol multiple times within each vigil. One repetition consisted of movement along the route from the initial waypoint to the end waypoint and then the return route to the original waypoint (see Figure 4). The rate and direction of movement through the scenario was fixed and controlled by the software, i.e. participants could not control the speed or direction of movement. Participants were 'moved' through the scenario along the path created in the open space between objects placed on the left- and right-hand side (walls, buildings, houses, rock formations, etc.). The length of the route was 165.4 m, so that each repetition (out and back) comprised moving 330.8 m through the scenario (see Figure 4). The practice phase consisted of a 15.3-minute vigil divided into five 3.06-minute periods on watch (i.e. route repetitions), and the test phase consisted of a 24.48-minute vigil divided into eight 3.06-minute periods. Participants were instructed to respond as quickly but as accurately as possible whenever they detected a target by clicking on its location using the mouse (a 'left mouse-click'). A correct response was defined as a mouse click within a 1-m spherical radius of a target. (This sphere was not visible to the observer, but it defined the area around each target that, when clicked, constituted a correct detection. A 1-m radius was selected to minimise the potential for confounding of detection performance by limitations in psychomotor accuracy (Fitts, 1954; Head & Helton, 2013).)

No feedback was provided during the practice or test vigils, and during the latter phase, participants experienced movement through the same sector employed during practice (out and back), but with a different random selection of targets along the path.

Experimental procedure

After providing informed consent and completing a demographic questionnaire, participants were briefed on the vigilance task and presented with images of the targets in order to familiarise them with the stimuli to be detected. They were then asked to wear noise-cancelling headphones and to complete the pre-task version of the DSSQ, after which they proceeded to the practice vigil, which consisted of five repetitions of the route (3.06 minutes per repetition; a 15.3-minute vigil), and the test vigil, which consisted of eight route repetitions (a 24.48-minute vigil). At the end of each vigil (practice and test) participants completed the NASA TLX (Hart and Staveland 1988) and the post-task DSSQ (Matthews et al. 1999, 2002), the order for which was counterbalanced across participants. The CITS (Matthews and Campbell 1998) was administered as part of the post-task version of the DSSQ. Upon completion of the post-test questionnaires, participants were debriefed, thanked and dismissed.

Experimental results

Practice vigil

Means and standard deviations for the performance measures are reported in Table 2. For this and all subsequent analyses the degrees of freedom were adjusted for violations of sphericity using Box's epsilon (Maxwell and Delaney 2004). A statistically significant effect for period on watch was observed for correct detections, $F(3,94) = 6.72$, $p < 0.001$,

Table 2. Means and standard deviations for performance measures ($N = 28$).

Practice vigil								
Proportion of correct detections								
Period on watch (3.06 min)								
1	2	3	4	5	Total			
0.56 (0.19)	0.57 (0.22)	0.62 (0.27)	0.75 (0.22)	0.76 (0.25)	0.65 (0.13)			
Frequency of false alarms								
Period on watch (3.06 min)								
1	2	3	4	5	Total			
20.71 (21.76)	19.07 (24.04)	16.96 (26.90)	11.82 (31.89)	14.93 (59.05)	16.70 (19.65)			
Response times to correct detections								
Period on watch (3.06 min)								
1	2	3	4	5	Total			
8.64 (2.68)	8.52 (2.41)	9.99 (2.99)	7.40 (2.89)	8.40 (3.23)	8.59 (1.20)			
Test vigil								
Proportion of correct detections								
Period on watch (3.06 min)								
1	2	3	4	5	6	7	8	Total
0.74 (0.17)	0.79 (0.18)	0.74 (0.29)	0.76 (0.25)	0.73 (0.26)	0.78 (0.18)	0.84 (0.18)	0.74 (0.26)	0.76 (0.16)
Frequency of false alarms								
Period on watch (3.06 min)								
1	2	3	4	5	6	7	8	Total
12.36 (53.49)	9.32 (36.76)	6.18 (18.89)	2.18 (4.44)	10.61 (45.03)	18.25 (78.32)	12.86 (53.43)	1.50 (1.90)	9.16 (26.07)
Response times to correct detections								
Period on watch (3.06 min)								
1	2	3	4	5	6	7	8	Total
7.66 (2.08)	8.35 (2.38)	9.95 (3.40)	7.41 (2.17)	9.07 (2.95)	8.10 (2.80)	7.81 (2.73)	9.81 (2.83)	8.52 (1.28)

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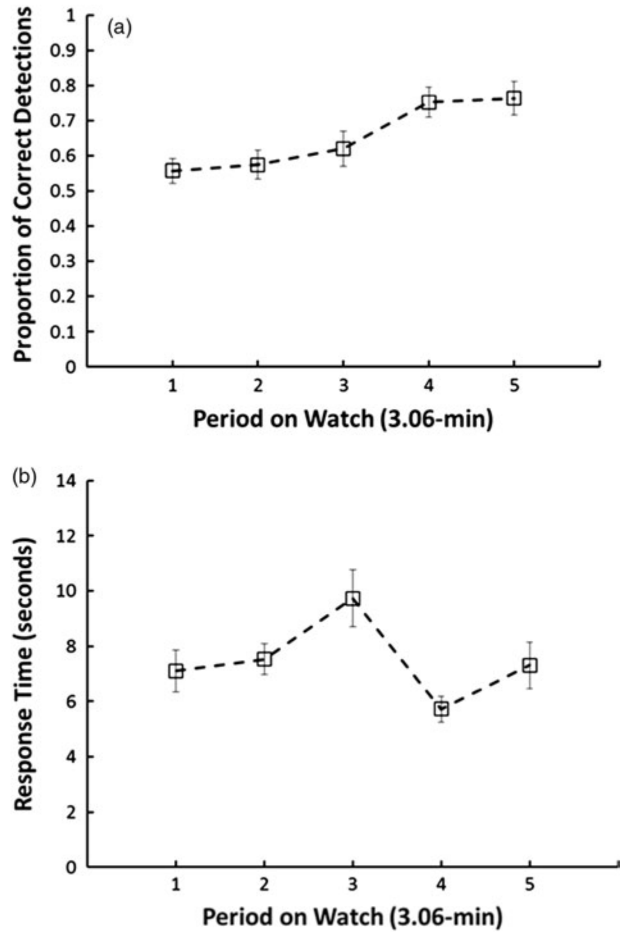

Figure 6. Proportion of correct detections (a) and median response time to correct detections (b) as a function of period on watch during the practice vigil.
Note: Error bars are standard errors.

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$\omega^2 = 0.11$ (see Figure 6a), in which detection performance in our 'vigilance on the move' paradigm actually *improved* with time on watch. Orthogonal polynomial trends analysis indicated a statistically significant linear trend, $F(1,27) = 19.37$, $p < 0.001$, $\omega^2 = 0.44$. The quadratic and cubic trends were not significant ($p = 0.57$, $\omega^2 < 0.001$, and $p = 0.12$, $\omega^2 = 0.02$, respectively). There was no statistically significant effect for false alarms ($p = 0.528$). For response time a statistically significant effect was observed for period on watch, $F(3,84) = 3.40$, $p = 0.020$, $\omega^2 = 0.07$ (see Figure 6b). As can be seen here, response time fluctuated across periods on watch. This impression was confirmed by an orthogonal polynomial trends analysis, which indicated a statistically significant cubic trend, $F(1,27) = 6.36$, $p = 0.018$, $\omega^2 = 0.06$. The linear and quadratic trends were not significant ($p = 0.58$, $\omega^2 < 0.001$, and $p = 0.24$, $\omega^2 = 0.01$, respectively). Potential reasons for this pattern are discussed below.

Table 3. Mean perceived workload scores (standard deviations in parentheses) for practice and test vigils ($N = 28$).

	Practice	Test
Global workload	40.45 (16.61)	35.77 (16.83)
Weighted mental demand	169.46 (120.05)	155.54 (125.20)
Weighted physical demand	14.46 (29.13)	16.43 (28.67)
Weighted temporal demand	70.18 (69.68)	46.96 (67.35)
Weighted performance workload	165.18 (93.81)	120.71 (77.52)
Weighted effort	145.36 (109.55)	126.61 (94.57)
Weighted frustration	42.14 (59.43)	70.369 (94.42)

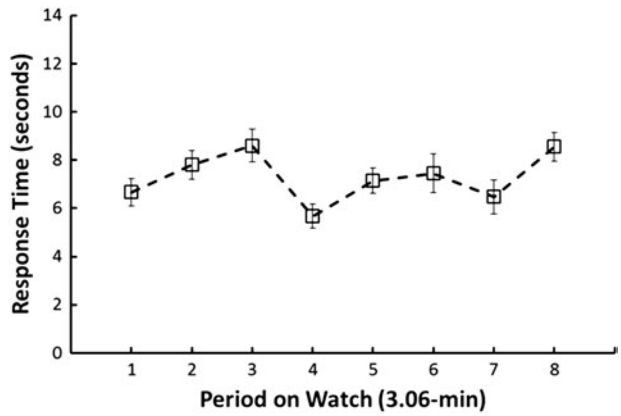

Figure 7. Median response time to correct detections as a function of period on watch during the test vigil.
Note: Error bars are standard errors.

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Test vigil

Means and standard deviations for the performance measures are provided in Table 2. No statistically significant effects were observed for correct detections ($p = 0.233$) or false alarms ($p = 0.280$). A statistically significant effect for period on watch was observed for response time to correct detections, $F(5,141) = 2.71$, $p = 0.021$, $\omega^2 = 0.03$, in which, again, response time fluctuated over time on task (see Figure 7). This was confirmed by an orthogonal polynomial trends analysis, which indicated a statistically significant cubic trend, $F(1,27) = 6.33$, $p = 0.018$, $\omega^2 = 0.13$. The linear and quadratic trends were not significant ($p = 0.52$, $\omega^2 < 0.001$, and $p = 0.34$, $\omega^2 < 0.001$, respectively).

Perceived workload and stress

Perceived Workload

Means and standard deviations for the TLX scores are given in Table 3. A marginally significant effect for global workload was observed, $F(1,27) = 3.62$, $p = 0.068$, $\omega^2 = 0.01$, such that global workload was lower for the test vigil than for the practice vigil (d = 0.28). A statistically significant effect was observed for performance workload, $F(1, 27) = 6.94$, $p = 0.014$, $\omega^2 = 0.05$, such that weighted performance workload was lower after the test vigil than after the practice phase ($d = 0.47$). There were no statistically significant differences between the practice and vigil phases for any of the other TLX scales ($p > 0.14$ in each case).

Stress and coping

The means and standard deviations for each of the three DSSQ scales and the three coping scales are summarised in Table 4. The change in stress state as a function of phase is illustrated in Figure 8. For task engagement a statistically significant

Table 4. Means (standard deviations in parentheses) for stress state (z-scores) and coping strategy ($N = 28$).

Pre-task	Post-practice	Post-test
	Task engagement	
0.38 (0.71)	0.17 (1.03)	−0.49 (1.02)
	Distress	
−0.71 (1.04)	−0.20 (0.81)	−0.21 (0.88)
	Worry	
0.78 (1.08)	−0.02 (1.00)	−0.03 (1.20)
	Task-focused coping	
–	14.86 (5.39)	14.46 (5.08)
	Emotion-focused coping	
–	7.50 (5.00)	8.68 (6.07)
	Avoidant coping	
–	6.43 (4.25)	8.68 (5.61)

Note: z-scores computed using normative means and standard deviations (Matthews et al. 1999; 2002).

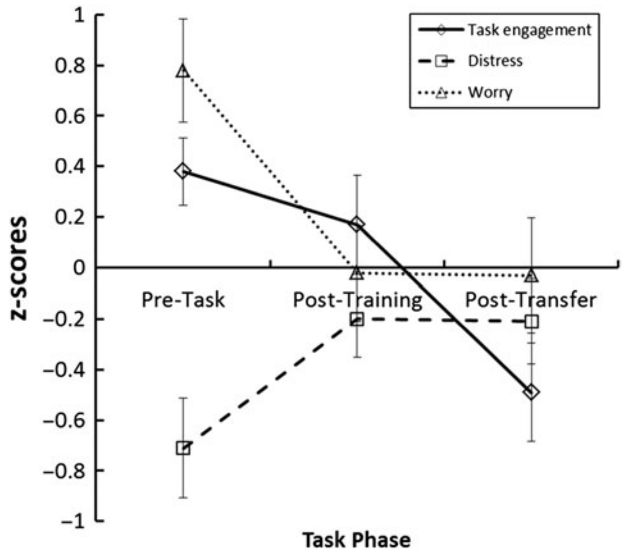

Figure 8. Pre- and post-task stress (z-scores) as a function of task phase.
Note: Error bars are standard errors.

phase effect was observed, $F(1,53) = 17.38$, $p < 0.001$, $\omega^2 = 0.13$. Post hoc tests indicated that task engagement significantly declined from the pre-task state to post-test vigil ($d = 1.24$). Post-task engagement was also lower after the test vigil relative to the post-practice state ($d = 0.65$). The difference between the pre-task and post-practice task engagement scores was not statistically significant ($p = 0.172$, $d = 0.30$).

For distress, a statistically significant phase effect was observed, $F(1, 41) = 5.14$, $p = 0.016$, $\omega^2 = 0.05$. Post hoc tests indicated that relative to the pre-task state, distress was higher after the practice vigil ($d = 0.49$). Post-test vigil distress was also higher than pre-task levels ($d = 0.48$), but the effect was not statistically significant after Bonferonni's correction was applied ($p = 0.037$; $\alpha = 0.05/5 = 0.017$). Distress scores for the training and test phases did not differ significantly from one another ($p = 0.933$, $d = 0.02$).

For worry, a statistically significant phase effect was observed, $F(1,49) = 16.84$, $p < 0.001$, $\omega^2 = 0.10$. Post hoc tests indicated that relative to the pre-task state, worry was lower after the practice vigil ($d = 0.74$) and after the test phase ($d = 0.75$). Worry scores for the practice and test phases did not differ significantly from one another ($p = 0.944$, $d = 0.01$).

There were no statistically significant changes in task-focused coping ($p = 0.651$, $d = 0.07$) or in emotion-focused coping ($p = 0.231$, $d = 0.24$) from the practice to the test vigil. A statistically significant increase in avoidant coping was observed, $F(1,27) = 5.05$, $p = 0.033$, $\omega^2 = 0.04$, such that avoidant coping scores were higher after the test phase ($M = 8.68$, SE $= 1.06$) than after the practice phase ($M = 6.43$, SE $= 0.80$; $d = 0.53$).

Discussion

The purpose for the present work was to determine whether results from the traditional vigilance paradigm could be replicated in a first-person perspective video-game context in which observers had to scan the virtual environment as they moved through a scenario. An additional goal was to describe the steps involved in developing a first-person video game-based vigilance task. There are cases in real-world environments in which 'vigilance on the move' occurs, most notably in transportation (e.g. driving, rail, maritime, military and law enforcement patrols). Transportation domains have also been significantly augmented by the explosion of PDA devices in which many individuals now do their computer-based work on the move (e.g. texting and walking). Our repetitive, monotonous target detection task was therefore created and its parameters were 'titrated' in order to investigate this novel task format which only promises to increase in a world of mobile and ubiquitous computing.

Performance improvement during practice

The significant increase in correct detections over periods during the practice phase suggests that participants learned to recognise target stimuli during their initial interactions with the task. Indeed, performance improvement was observed

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during the practice phase. One possible explanation for this improvement is that participants learned to both detect targets (perceptual learning) and to make accurate mouse-click responses (psychomotor learning), as both of these factors can influence performance (see Hancock and Caird 1993; Hancock and Newell 1985). Our present data cannot unequivocally distinguish between these sources, although we believe that psychomotor learning is unlikely in the present context because (1) we selected a relatively large radius to minimise variability in psychomotor performance and (2) there is evidence from previous studies using this task (Schmidt et al. 2012; Szalma et al. 2014; Teo et al. 2012) that the performance improvement during practice is eliminated (i.e. observers achieved stable performance levels early in the watch) when brief video clips were added to the instructions to illustrate the nature of the targets. However, these findings were obtained with a constant sphere radius designed to avoid the aforementioned psychomotor performance confounds. Thus, the potential interactive effects of perceptual and psychomotor learning in this paradigm remain to be fully articulated.

The vigilance decrement

In contrast to many traditional studies, no performance decrement over time was observed in this present study. It would be premature, however, to conclude that video game or first-person motion-based vigilance tasks are immune to the vigilance decrement. This is because these present results may be due to factors such as the respective rate of movement selected. For instance, it is possible that the rate of movement was too low to induce a decrement (i.e. low event rates attenuate the decrement function; See et al. 1995; Warm and Jerison 1984). Alternatively, the absence of a decrement may have been due to a movement rate that was too fast for initial performance to be high (i.e. mean initial detection rate in the test vigil was 0.74).

With respect to response time, which fluctuated across periods in the present study, the pattern may reflect transient fluctuations in attention (Smith, Valentino, and Arruda 2003). Alternatively, the rise and fall in response times may be a result of the movement-based, continuous nature of the task and the resultant necessity for blocking time on task in terms of numbers of route repetitions. Traditional vigilance is highly orchestrated in terms of blocks of time on task (periods on watch). Such discretisation may have introduced fluctuations because of the continuous movement-based nature of the task. In particular, the continuous presence of perceptual change characteristic of the ‘vigilance on the move’ task is substantially different from the perceptually impoverished context in which display stimuli are presented in traditional vigilance research.

Although the vigilance decrement is the typical finding in research (See et al. 1995), it is not ubiquitous. There have been a number of instances in which traditional vigilance tasks do not induce a decrement, even though the tasks are monotonous (e.g. Carter, Russell, and Helton 2013). It may be that the monotony of a task is linked not only to the degree of stimulation from the display but also to the appraisals of the task by the observer regarding the meaningfulness of the task relative to their immediate goals. The former may be conceptualised as ‘objective monotony’ and the latter as ‘subjective monotony’ (cf. Melamed et al. 1995; Shirom, Westman, and Melamed 1999). One critical issue for future work is to investigate how objective and subjective monotony interact to affect vigilance.

Perceived workload and stress

The absence of a performance decrement does not necessarily indicate that the monitoring task was not demanding or stressful. Although global workload scores were slightly below (35–45) the mid-range of the scale, which contrasts with previous vigilance studies in which these scores have been reported as substantially higher (60–70; Warm, Dember, and Hancock 1996), mental demand was relatively high. Furthermore, this mental demand, as well as performance workload, and effort contributed most to the overall perceived workload (see Table 3). This in itself is a somewhat different pattern than that observed in previous research, in which mental demand and frustration are typically the two greatest contributors to the workload of vigilance (Warm, Dember, and Hancock 1996). Thus, the video-game environment may both impose less overall workload and induce a different workload profile than traditional vigilance. This suggests that although the game environment imposes high mental demand, it may be less aversive for participants than traditional tasks.

This interpretation is tempered, however, by the results from the DSSQ and for coping, which indicated that task engagement declined and distress and avoidant coping increased. This pattern of results is consistent with previous vigilance research (Matthews and Campbell 1998; Warm, Matthews, and Finomore 2008; Warm, Parasuraman, and Matthews 2008), in which task engagement and worry typically decline and distress increases. Task engagement is associated with the appraisal of effort, distress is associated with the appraisal of perceived overload of processing capacity, and decline in worry reflects diversion of attention away from self (Matthews et al. 2002). It may be that the video-game environment effectively diverts attention away from self-oriented contemplations, but that this diversion did not prevent the task from inducing resource depletion (as indicated by the pattern of change in task engagement and distress). These

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observations suggest that efforts to make the video game-based task monotonous were to a degree a success, as this pattern has also been observed in traditional vigilance studies (Warm, Dember, and Hancock 1996, Warm, Parasuraman, and Matthews 2008). However, further empirical examination of this issue is certainly warranted.

The energetic cost of vigilance

The absence of a performance decrement may indicate that the video-game environment does not induce the decrement function as 'created' by the more traditional extant vigilance tasks (cf. Hancock 2013). However, the observed decline in task engagement is typical of many reported vigilance tasks (e.g. Helton, Warm, and Matthews 2009; Szalma et al. 2004). This suggests that the video game-based vigil was not sufficiently engaging to prevent the decline in subjective experience of task engagement and task-focused coping. The increased effort observed after the test phase likely indicates an established form of compensatory effort (Hancock and Warm 1989; Hockey 1997) in response to the two phases of monitoring. Thus, participants were able to preserve their performance, but they did so at an energetic cost (Hancock 1996; Hancock and Warm 1989). A video-game based vigilance task is thus not immune to 'latent performance decrement' (Hockey 1997). The pattern of results (i.e. reduction in performance workload, the stability of performance, but the decline in task engagement and the increase in distress) suggests that the task display itself may not have been demanding, but that the monotony of the vigil and the absence of opportunities for active interaction with the task (a main characteristics of traditional monitoring tasks; Hancock 2013) did prove stressful.

Implications of 'vigilance on the move' for vigilance theory

The dominant theory of vigilance and the explanation for the vigilance decrement derives from the energetic resource perspective on human cognition and performance (Hockey, Gaillard, and Coles 1986). From this perspective, the vigilance decrement accrues from a progressive (i.e. with time on task) decline in mental resources at a rate faster than they can be replenished (Parasuraman, Warm, and Dember 1987; Warm, Dember, and Hancock 1996). This resource-based explanation has received substantial empirical support in terms of not only performance but also perceived workload and stress (Warm, Dember, and Hancock 1996; Warm, Parasuraman, and Matthews 2008) and in neurological response (Warm et al. 2012). It has recently been argued (Hancock 2013) that the vigilance decrement and accompanying energetic costs are iatrogenic, i.e. that they are a result of poor task and display design rather than an inherent limitation in attentional capacity per se. Although Hancock (2013) sought to dissociate sustained attention from vigilance (terms that have traditionally been used interchangeably), he did not argue that the mechanisms that regulate the underlying cognitive capacities could not be common to these processes. That is, the cognitive processes may be the same in both iatrogenic vigilance tasks and in naturalistic sustained attention contexts.

Presumably, the resource-based explanation for vigilance applies to both traditional, static tasks as well as tasks that more closely approximate operational conditions. It may be that current theory is incomplete and needs to be modified to account for differences in the *kinds* of environmental stimuli (e.g. relevant vs. irrelevant information) to which attentional resources are distributed rather than simply the *quantity* of resources allocated. Future research should seek to separate the information processing demands from the stress of monotony and boredom as sources of resource depletion in vigilance (cf. Hitchcock et al. 1999; Scerbo 1998a).

Implications for a video game-based paradigm for sustained attention

As a new experimental paradigm, the task we created for the present work has principally served to establish a foundation for further programmatic, experimental research (Szalma et al. 2014). The results indicated that the task did capture some elements of traditional vigilance (e.g. high mental demand, a decline in task engagement and an increase in distress; the sensitivity of performance to task pace), although there were substantial differences in other respects (relatively low global workload and the absence of a performance decrement for certain measures and even an increment in others). Continuing investigations should therefore seek to explore the generality of the present findings and to investigate the unique characteristics of video-game contexts in moderating the performance, workload and stress effects typically associated with monitoring tasks.

A further issue to consider is whether the video-game format can be effective in attenuating performance decrement. One goal for the present work was to develop a monotonous task, i.e. to develop a vigilance task within a video game. However, it is possible that the monotony could be eliminated from a video game-based monitoring task. As has been recently noted (Hancock 2013), many instances of performance decrements in monitoring tasks may have been induced by an unintentional poor design of the displays and tasks themselves. That is, the vigilance decrement, and the concomitant high workload and stress, may be *iatrogenic*. Hancock (2013) also raises the spectre that the decrement in traditional laboratory vigilance tasks results from a 'titration' of conditions by experimenters in order to induce the decrement pattern

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so prototypical of the area. In our present work, we have indeed illustrated this process through our selection of factors such as rate of locomotion and stimulus conspicuity in order to achieve patterns of objective and subjective response familiar to the vigilance research community.

Given these concerns it is important to note that our objective was not to convert a vigilance task into a game, but to use a game to create a vigilance task, in essence to create an *anti-game*. However, the workload, stress and monotony associated with monitoring tasks may potentially be ameliorated by introducing game-like elements to a vigilance task (i.e. to make it less monotonous and more interesting and engaging). There has been substantial recent interest in the potential benefits of video games (Granic, Lobel, and Engels 2014), although there are limits to its effectiveness (e.g. Hawkins et al. 2013). There is recent evidence that 'serious games' may have general performance benefits (Wouters et al. 2013), but to date this has not been explored in monitoring tasks. One problem is that the features of games that facilitate learning include aspects of meaningful and interactive activities (Annetta 2010). Vigilance tasks often do not (currently) possess these elements, but it is not yet determined how monitoring tasks can be reconfigured to include these features.

An interesting question for future research in this paradigm is therefore whether design of the display and the task can be made more engaging or more enjoyable (Hancock, Pepe, and Murphy 2005), based on the operator's individual interests (Hancock, Hancock, and Warm 2009; Szalma 2009; Szalma and Taylor 2011), and whether such interventions serve to reduce the everyday, real-world problems of monitoring. Of course, in some contexts such as IED detection, driving, train operation and maritime monitoring (i.e. ship 'lookouts'; Alluisi 1966) such task manipulation may not be possible (i.e. many of these particular task characteristics are 'designed' by nature or by a human enemy). However, our present work does serve to establish a video-game paradigm for vigilance and raises the possibility that some industrial monitoring tasks may be configurable to be more 'game like' than has traditionally been the case. It is theoretically possible to create environments that facilitate resource replenishment (e.g. see Kaplan 1995), but whether monitoring tasks can be so transformed is an interesting but mostly unexplored challenge.

Video-game experience and sex differences

One limitation of the present work is that the effects of video game-based training may depend on participant sex and experience with video games. Previous research has indicated that both of these factors can influence performance on laboratory tasks (e.g. Boot et al. 2008; Cain, Landau, and Shimamura 2012; Green and Bavelier 2003; Young, Sutherland, and Cole 2011; but see also Feng, Spence, and Pratt 2007; Richardson, Powers, and Bousquet 2011; Smith, Stibric, and Smithson 2013), including previous work with the task used in the present investigation (Schmidt et al. 2012, 2013). However, the present sample size (12 females, 16 males) was largely insufficient to generate definitive analysis of the data for these potential effects. In addition, 20 participants (6 females) reported that they played video games (ranging from playing less than 1 hour to playing 5–6 hours per day) and 8 participants (6 females) reported that they did not play video games at all (zero hours per day). A χ^2 test of the frequency distributions for males (14 players, 2 non-players) and females (6 players, 6 non-players) was statistically significant, $\chi^2(1) = 4.72$, $p = 0.030$. Hence, one question for future investigation is whether improvement in detections over periods observed in this study during the practice phase could be moderated by participant sex or video-game experience.

Potential software issues in vigilance task development

In developing 'vigilance on the move' several issues were identified that do not generally occur in traditional vigilance research. These problems were instructive in that they underscore the unique challenges of designing a vigilance task featuring first-person movement, and how these difficulties can be resolved. We have, in the process of development, discovered a series of reasons why vigilance on the move is difficult to create and operationalise, and hence some reasons why the traditional 'static' paradigm has continued to predominate. The following issues were specifically identified:

a. The software may define a target as 'visible' even in cases in which the target does not actually appear on the screen. The reason for this is that the system may define a stimulus as visible if an imaginary line from the camera location can be made to a target, this regardless of whether it actually is visible to the participant (e.g. the target is behind a wall or on a different section of the route, or it is displayed far in the periphery but a participant has not yet turned within the scenario at the relevant waypoint). This issue may be resolved by placing additional objects in the environment to facilitate target occlusion. Target occlusion (e.g. using walls or other large objects) can 'shield' targets from the line of sight determined by the software.
b. To the extent possible the scenario path should be linear in order to simplify control of such target occlusion and emergence on the screen, and also to increase the monotony of the task.

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c. If a participant responded to a non-target area by clicking the mouse multiple times in rapid succession (i.e. committing multiple false alarms), the software recorded each mouse click as a separate response. This can be corrected by ensuring that mouse clicks which occurred within 200 ms of previous click would not elicit data recording. This is designed to prevent the creation of multiple false alarms corresponding to a single detection decision by an observer.
d. In initial tests, when participants correctly detected a target, it was removed from the scene. This 'disappearance' of targets after detection inadvertently provided performance feedback information to participants regarding their response accuracy (i.e. that they had indeed clicked on a target because non-targets were not removed from the screen when participants responded to them). The task should therefore be carefully designed so that, as in the present experiment, targets are not removed when participants click on them.

Video game-based vigilance: factors to consider in task design

The present study and the issues described above provide the basis for an approach to development of video game-based sustained attention tasks. We now address the specific characteristics of the video-game vigilance task that distinguish it from more traditional vigilance tasks.

Stimulus background and observer 'movement'

In contrast to static displays, the present vigilance task was created via a continuously moving, first-person perspective virtual environment comprising multiple non-target objects (i.e. stimuli that were irrelevant to the target detection task). However, video-game displays are, by design, more rich in perceptual information than traditional vigilance tasks. That is, video-game displays are designed to be interesting and to capture and hold attention. Moreover, in video games, individuals can control their movement in the virtual environment, but in vigilance observers typically have limited autonomy in how they may respond to the task environment (Hancock 1998; 2013; Scerbo 1998a, 1998b).

To capture the monotony and lack of autonomy typical of certain real-world vigilance contexts, we created a task in which the observer was 'moved' repeatedly through the same virtual environment. This repetition can potentially offset the stimulating effect of the perceptually rich content and control of the environment. Participants were also prevented from controlling the direction of movement, and they could not pan their viewpoint to any direction other than that preset. They were thus prevented from actively exploring the environment, which itself can influence observer' response (Gunn et al. 2005; Parsons 2007).

Movement rate

The movement rate must be carefully titrated. Results from our work indicated that a rate of movement of 2.2 m/s resulted in a floor effect while a rate of 1.5 m/s can induce a ceiling effect (see Szalma et al. 2014). Variations in movement rate are functionally equivalent to the effects of event rate in a traditional vigilance experiment; cf. Warm and Jerison 1984).

Target placement

Traditional vigilance tasks comprise two-dimensional static displays, in which stimuli appear either without movement or with movement in two dimensions (e.g. Finomore et al. 2013; Funke et al. 2010; Montague and Webber 1965). A video-game environment, however, poses a different challenge as targets may well first appear in the periphery, but move to the centre of the screen, and then out into the periphery again as the observer 'moves' past them in the environment (Gibson 1966, 1979). First-person perspective motion through a scene captures the elements of real-world monitoring contexts in which observers move, but also poses a novel challenge for creating a task in which the presentation of stimuli is under a high degree of experimental control (e.g. stimulus size, location). Moreover, when moving through an environment, the features (size, perspective) of objects also changes. This experience of optic flow (Gibson 1979; Hancock and Manser 1997) should be considered in determining target placement for vigilance on the move, in order to ensure control over target size at its onset (i.e. when it becomes visible to the observer).

Target salience

Target salience is relatively easy to control psychophysically in traditional static displays, particularly in the perceptually impoverished contexts in which such stimuli are usually embedded. In some cases a visual mask can be interpolated in order to manipulate target saliency (e.g. Temple et al. 2000; see Figure 1h). In the video-game environment, the use of a visual mask is possible (e.g. in VBS2 it could be accomplished by introducing natural elements such as fog or smoke into the

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scenario), but an alternative is to manipulate the degree of similarity in colour/shading of the target and the proximal objects that surround it. For instance, placing the yellow container near a similarly light-coloured burlap sack or light-coloured walls proved effective for introducing that target in the vigilance scenario. As in traditional, discrete trial vigilance tasks, the objective here is to develop targets and target placement locations that do not easily capture attention but that remain detectable by participants *if they are paying attention*.

A second issue concerning target salience emerged from the first appearance of such targets as observers moved through a scenario. Spontaneous appearance of targets within this continuous flow results in 'pop-out' effects that artificially boost target saliency. We resolved this issue here by placing targets behind other objects so that they are occluded when the software first renders them into the virtual scene. However, they do then gradually become visible as the participant moves through the environment and passes by the occluding object (see also Hancock and Manser 1997). The movement thus becomes the means by which targets are presented to the observer. This approach also served to facilitate precise specification of target-onset time, which allowed for response time to correct detections to then be accurately computed.

Blocking of time on task

Vigilance performance is typically analysed in blocks of trials (often referred to as periods on watch). The duration of a period is usually largely arbitrary and is based on the most convenient way to ensure equivalent numbers of events for both signals and non-signals within each block. Although early research often utilised relatively long watch keeping periods (e.g. 30 minutes; Mackworth 1948, 1950), in recent research blocks of time can vary from 2 minutes for short duration vigils (Temple et al. 2000) to 5–10 minutes for nominally longer vigils (e.g. Becker, Warm, and Dember 1994; Szalma 2009, 2011; Szalma et al. 2004, 2006).

This approach can, in principle, also be used in video game-based tasks, but we have found that a more convenient alternative is to 'create' watch periods based on repetitions of movement through the scenario. In this work, a scenario was created in which participants 'moved' through an environment to an end point, at which point in time they returned to their starting point via the reverse route. This movement was then repeated multiple times, with each trip out and back constituting the basic time unit. Thus, periods in the present study were defined in terms of the number of route repetitions completed. In addition to facilitating the blocking of time on task, this approach also served to increase monotony, so that the video-game format could still foster this crucial aspect of monitoring demand.

Defining a correct and incorrect response

In most vigilance research observers respond by pressing a switch, a button or a key on a keyboard (e.g. the space bar). Although this mode of responding is possible in a video-game context, one difficulty is that if the observers respond during a time epoch in which the target is visible, their response is ambiguous. Thus, they may be correct (i.e. they detected a target) or it may be a false alarm (i.e. they responded because they falsely believed there was a target in a location on the screen at which it was not actually present). In either case, if there is a key press response during the epoch it would be recorded as a correct detection. Thus, a key press when a target is present *may* indicate that the observer detected the target, if one assumes that he/she was attending to the area in which the target was placed in the scene. Such responses would, however, be indistinguishable from those in which the observer responded to a non-target object (or indeed possibly no object at all) in another location on the screen.

An alternative response format that distinguishes between these two outcomes is to ask observers to respond to targets via a mouse click on the location in the virtual environment at which they believe a target has appeared. This allows for unambiguous determination of whether the observer actually detected a target or responded to a non-target stimulus that appeared in another location simultaneously. However, requiring a mouse click on the location necessitates defining a volume around the target that, when clicked, is scored as a correct detection. The radius that defines the correct detection around a target should be specified and, in most cases, determined via pilot testing.

Of course, the target area issue is a spatial analogue to the problem of defining the temporal window in which a response to a discrete stimulus presentation is scored as a correct detection. The optimal size of this 'click-area' depends on (1) the pace of movement through the scenario, as mouse-click accuracy is more difficult as the pace of movement increases, and (2) size of the target. Providing an adequate volume for acceptable mouse clicks for accurate responding is thus necessary to avoid confounding of target detection with limitations in psychomotor accuracy as described by Fitts (1954). The radius must be carefully selected to prevent learning or performance effects related to the accuracy of pure psychomotor control.

For the task used in the present study, preliminary work established that a 1-m radius was best suited for the vigilance task compared to a 0.5-m radius hemisphere. This was based on post-vigil participant feedback from prior procedures. Such participants had indicated that mouse accuracy was relatively poor and that mouse speed was too slow to click on targets.

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The increase in hemisphere size allowed for greater latitude for mouse clicks on targets and reduced the number of motor-related as opposed to perceptual-related misses. One area for future research then is to examine the conjoint effects of psychomotor accuracy and vigilance on performance, workload and stress (cf. Head and Helton 2013).

In our task paradigm, a false alarm is defined as a mouse click that occurs on an area of a scene in which no target is present (i.e. outside the area defined as a correct detection). Misses are defined as a failure to click on a target within the time interval in which it appeared and was visible in the scenario. In contrast to previous vigilance tasks using discrete trials, in our continuous video game-based approach it is possible to commit *both* a false alarm and a miss within the same time epoch. For instance, an observer can click on an area of a scene in which no target is present (i.e. commit a false alarm) and simultaneously fail to attend to a target visible in another part of the scene (a miss). Yet this pattern is, of course, true of many real-world circumstances.

A limitation to performance measurement

The continuous task environment limits the order of performance that can be recorded. An additional challenge with using dynamic vigilance on the move is the difficulty in defining the occurrence of a non-target event. In traditional vigilance, stimuli are presented in discrete trials which comprise a fixed number of non-signal events, so that the rate of background events can be controlled and false alarm probabilities computed. In the continuous video-game environment, however, the number of false alarms committed is indefinite, limited only by the number of times an observer can press the mouse button (and of course given the 200-ms suppression window for multiple clicks). Thus, one can record false alarm frequency, but determining the proportion of these false alarms (or the response time to false alarms) requires an arbitrary definition of the time epoch in which they occurred. This issue has yet to be resolved but one could argue that we need to recast what is thought to be a false alarm in the real world.

Conclusions

In conclusion, the use of a video-game platform which provides a dynamic environment and variable stimuli can enable development of vigilance tasks that resemble those that require the observer to move through an environment. We have, in essence, created an 'anti-game'. We have accomplished this by creating a scenario in which observers 'moved' through a route multiple times, so that the irrelevant stimuli would decline in novelty with time on task. However, there are challenges that accompany the use of first-person perspective movement in a vigilance task, specifically the loss of control at the level achieved in typical discrete trial approaches. The issues to be considered in further developing a video game-based monitoring task are specified in the procedural guidelines provided in the Appendix.

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Appendix

General procedural guidelines for developing video game-based vigilance tasks

- The pace of movement through the scenario will influence performance by constraining time available to search for and identify targets. Hence, movement speed is a useful parameter for manipulating task demand.
- Speed of movement also serves to determine a number of other task characteristics. Specifically, selection of the rate of movement influenced the total number of signals presented, the duration of a route completion and the overall duration of the vigil. The number of repetitions of the route should be adjusted to achieve the desired effect of monotony.
- The number of target categories should be sufficient to avoid making the task too simple but not so many that vigilance effects are confounded with memory set size. Four or five targets are recommended based on the present and previous work.
- Placement of targets in a scenario should ensure that there is high spatial and temporal uncertainty. In 2AFC pilot testing, targets should be placed in both peripheral and central locations within the scenario in order to titrate the salience of each type of target to be detected.

- Use objects to occlude targets so that they appear naturally as the observer moves through a scene.
- Target conspicuity can be further titrated by adjusting the amount of clutter of irrelevant objects in the scenario.
- Adjusting the number of route repetitions can be used to determine the duration of a period on watch for evaluating performance change over time on task.
- Use of repetitive movement through scenes can simulate the monotony typical of vigilance tasks.
- The spatial range of correct and incorrect responses for mouse clicks on targets to be detected should be defined based on pilot tests to establish the desired level of psychomotor accuracy.

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