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Rest is best: The role of rest and task interruptions on vigilance

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ABSTRACT

We examined the impact task interruptions have on visuospatial vigilance in two experiments. In the first experiment participants were randomly assigned to one of three interruptions: participants were given a complete rest (rest), participants completed an alphanumeric vigilance task (letter), or participants performed the primary vigilance task (continuous). In the second experiment participants were randomly assigned to one of the conditions from the first experiment or to two further conditions, in which participants (spatial memory) performed a spatial match to sample task, or participants (verbal memory) performed a letter match to sample task. Vigilance performance post-interruption was best for rest, worst for continuous, and varied for the other interruption tasks. Overall, the results suggest the vigilance decrement is due to the repeated use of particular executive resources, but there may, in addition be domain specific interference when the primary task and activities during a break make use of the same resources.

1. Introduction

People and other animals often have to process stimuli over time while attempting to detect predetermined signals. Psychologists refer to this process as vigilance, sustained attention or vigilant attention (Langner and Eickhoff, 2012). People are, however, often unable to maintain their level of signal detection performance over time. This performance decline is labelled the vigilance decrement and is assessed by an increase in response time, a decrease in signal detections or both over time. There has been on-going debate amongst psychologists regarding the cause of the vigilance decrement since the original finding of the phenomena by Mackworth (1948). Essentially the debate is over whether the decrement is directly due to the task's monotony or under-load, which induces a state of cognitive task disengagement, or instead due to the task's requirement for continual processing which results in fatigue and cognitive resource depletion (Hancock and Warm, 1989). The later, resource depletion theory, is arguably the predominate view held by the majority of active vigilance researchers, but the alternative under-load theory continues to have adherents who periodically develop slightly different variants of the under lying theory (Ariga and Lieras, 2011).

Indeed, resource theory applied to sustained attention or vigilance tasks is often criticized (Navon, 1984). Much of this criticism may actually result from resource theorists not being clear about the information processing resources utilized during vigilance tasks or providing strict enough tests of resource theory. Recently, for example, resource theories of vigilance have been fused with ego depletion findings discovered by social psychologists by critics of resource theory (Kurzban, Duckworth, Kable, and Myers, 2013) and researchers hoping to find some sort of compromise between the prevailing under-load (boredom or monotony theory) and over-load (resource theory) models of vigilance (Langner and Eickhoff, 2012). The decline in vigilance performance over time, or the vigilance decrement,

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is according to the resource theory perspective due to reductions in specific executive processing resources (Davies and Parasuraman, 1982; Helton and Russell, 2012; Helton and Warm, 2008; Warm, Parasuraman, and Matthews, 2008). The decline is not due to a general depletion of some non-specified ego power or will power required to sustain effort on an otherwise monotonous task. Although willpower depletion may or may not occur; it is not the explanation for the vigilance decrement purported by resource theorists. Resource theorists, moreover, posit a strong relationship between sustained attention and working memory processes. Vigilance tasks placing greater memory demands on participants are more likely to result in declining performance (Parasuraman, 1979). Many theories of working memory similarly indicate an attention component in working memory processes (Chen and Cowan, 2009; Cowan, 1995; Kane and Engle, 2002).

Researchers have noted a coupling between vigilance performance and cerebral blood flow (CBF) in the anterior cingulate cortex (ACC) and prefrontal cortex (Fan, McCandliss, Fossella, Flombaum, and Posner, 2005; Lawrence, Ross, Hoffman, Garavan, and Stein, 2003; Lim et al., 2010). The vigilance decrement is matched by declines in CBF with time-on-task (Hitchcock et al., 2003; Shaw et al., 2009). Brain imaging studies of working memory also note activation in the prefrontal cortex and ACC (D'Esposito et al., 1995; Gevins, Smith, McEvoy, and Yu, 1997; Smith and Jonides, 1995). Overlap in neural processing resources between working memory and sustained attention is plausible.

Wickens (1976, 2008) advocated a multiple resource theory (MRT) account of task performance with different pools of task specific mental resources. Caggiano and Parasuraman (2004) investigated MRT by pairing a visuospatial or a verbal working memory task with a visuospatial vigilance task. There was a significant vigilance decrement when the vigilance task was paired with a visuospatial working memory task, but not when paired with a verbal working memory task suggesting domain specific sharing of resources between working memory tasks and vigilance. Helton and Russell (2011, 2013) explored this topic by examining the impact of concurrent verbal and visuospatial working memory demands on alphanumeric (verbal) and visuospatial vigilance. In their studies, the vigilance decrement was exacerbated by concurrent working memory load, regardless of memory load domain, thus indicative of domain general effects. Like Caggiano and Parasuraman, they did, however, find additional domain specific interference between the pairing of a visuospatial vigilance task and a secondary spatial memory task, even when the memory load was not concurrent (Helton and Russell, 2013).

The interrelationship between working memory and sustained attention processes does provide the opportunity to test the resource theory account of the vigilance decrement. From the resource theory perspective, vigilance performance recovers when the specific information processing resources that are depleted are allowed to recover. Rest breaks have been found to improve vigilance performance (Bergum and Lehr, 1962; Ross, Russell, and Helton, 2014), but not always. Sometimes the rest break does not enable full rest because the participant is unaware of how long or when the break will end (see Lim, Catherine-Quevenco, and Kwok, 2013). Essentially, without informing the participant, the break may itself become a vigilance task (essentially a long inter-stimulus interval). A real rest, with information regarding task resumption, should result in performance recovery.

In addition, resource theory implies that the ability of an interruption task to afford performance recovery is contingent on how much the interrupting task actually overlaps with the specific processing resources of the primary vigilance task. In the present study, we conducted two experiments where we compared visuospatial vigilance performance after different interruption conditions. The primary focus of the experiments was to compare the impact of rest breaks and continuous task performance (no-interruption) with other interruptions varying in resource demands. If resource theory is correct, performance following the interruption should be best for rest, worst for continuous, and differentiated for the other interruption groups.

2. Experiment 1

In experiment 1, participants performed a demanding visuospatial vigilance task which has been found to produce a vigilance decrement in short durations, less than 5 min (Helton and Russell, 2013). Resource theorists have suggested that long durations are not necessary to illicit the vigilance decrement. If the task demand is intense enough, the vigilance decrement can occur extremely rapidly. Many proponents of current under-load theories also suggest sustained attention can be assessed in short durations (Robertson, Manly, Andrade, Baddeley, and Yiend, 1997). During the visuospatial vigilance task participants experienced one of three interruption conditions: participants were given a complete rest with timing information, participants performed the primary visuospatial vigilance task continuously, or participants completed an alphanumeric vigilance task also known to produce a decrement in short durations (Temple et al., 2000). All participants then resumed the visuospatial vigilance task. Our primary goal was to see whether a task-switch to another task requiring sustained attention would enable some recovery. If resource theory is correct, performance following the interruption should be best for rest, worst for continuous and in-between rest and continuous for a task placing similar, but not exactly the same processing demands on the participants as the primary vigilance task.

3. Methods

3.1. Participants

Two hundred and sixty-six (183 female) students ranging in age between 17 and 60 years old (M = 19.9 years; SD = 4.9) served as participants. The study was carried out along principles laid down in the Helsinki Declaration and was approved by the University Human Ethics Committee.

3.2. Experimental design

The present experiment was a 3 interruption task (rest, continuous, letter detection vigil) ×2 block (pre-interruption vs. post-interruption) experimental design. The interruption task was varied between-subjects and block was a within-subjects factor.

3.3. Procedure

Stimulus presentations and all stimulus and response timing were controlled using E-Prime 2 Professional (Schneider, Eschman, and Zuccolotto, 2002) running on 3.40 GHz Intel i7 2600 PC computers. Stimuli were displayed on 29.5 × 47.2 cm Phillips 225B2 LCD monitors with resolution 1680 × 1050 pixels refreshed at 60 Hz. Screens were positioned at eye height approximately 50 cm from participants whose heads were not restrained. Participants were run in groups of up to 36 at a time with each participant seated at an individual cubicle workstation within a larger computer laboratory.

In our experiment all participants completed multiple blocks of spatial vigilance trials, each block lasting 52.8 s. These blocks were the same for everyone. Participants monitored the repetitive display of a small black oval shape (1.75 × 1.05 mm) displayed for 200 ms at the rate of one every 1200 ms on a gray background (E-Prime colour gray). Participants were instructed to press the spacebar whenever an oval appeared at a target far location 25 mm to the left or right of a central fixation " + " (E-Prime silver Arial 16 font) and to make no response to neutral near ovals placed 20 mm from fixation. Responses made within 1200 ms of the onset of an oval at a target location were classified as hits; responses made within 1200 ms to ovals at neutral locations were classified as false alarms. Each of these blocks comprised 44 location detection trials of which 8 targets were presented at the far location and 36 neutral stimuli were presented at the near location. These were balanced for which side of the center of the screen the dots were presented and a different random order was used for each participant.

Between the first two blocks of the visuospatial vigilance task and a subsequent block of the visuospatial task there was an interruption during which one of three kinds of activity took place (see Table 1). Participants were randomly assigned to these three groups. One group of participants (Rest) was given a complete rest during the interruption. A message appeared on the screen for 3.7 s every 19.7 s informing them of the duration of rest that remained before they resumed the second block of the vigilance task. The total interruption was approximately 1.76 min. The second group (letter detection) completed a slightly different vigilance task during the interruption. These participants had to press the space bar whenever they detected a rarely occurring "O" among more common "D" and backwards "D" stimuli (see Temple et al., 2000). The total interruption was approximately 1.76 min. For the third group (Continuous) the interruption was identical to the preceding and following blocks of the vigilance task (they did the vigilance task for the interrupting period).

Prior to the experimental trials all participants first completed instruction and practice trials for the location detection and letter detection tasks although only the letter detection group actually completed any letter detection trials during the interruption period. All participants were then informed that they would complete location detection trials but that these may be interrupted by the task they had just practiced, interrupted by a rest, or that they would continue the location detection task without interruption.

4. Results

Our primary comparison was between performance on the first two pre-interruption blocks (averaging block 1 and 2) and the post-interruption block. This ensured the comparisons across the conditions were made at equivalent time points during the experiment.

4.1. Target detection sensitivity

For the pre-interruption and post-interruption blocks percent hits (correct detections) and percent false alarms were recorded for each participant. We calculated A', a signal detection metric of perceptual sensitivity, from the participant's hit and false alarm rates (see Macmillan and Creelman, 2005). A' is an indicator of how well the participant could discriminate the target from neutral stimuli independently of their tendency to simply respond or not (their bias). The means and standard deviations of A' are presented in Table 2. We employed a 3 (interruption condition) ×2 (block: pre-interruption vs. post-interruption) mixed analysis of variance. A' declined significantly from pre-interruption (M = .911) to post-interruption (M = .900), $F(1, 263) = 5.49$, $p = .020$, $\eta_p^2 = .02$. In addition there was a significant block by condition interaction, $F(2, 263) = 7.88$, $p < .001$, $\eta_p^2 = .06$. The main effect for interruption group was not statistically significant, $F(2, 263) = 2.50$, $p = .084$, $\eta_p^2 = .02$. To further explore the interaction, we performed a one way ANOVA for the pre-interruption block. This established that interruption groups did not differ in pre-interruption sensitivity, $F(2, 263) = 0.18$, $p = 0.881$, η_p^2.00. We then performed separate paired t-tests comparing the pre-interruption and post-interruption performance for each interruption group. The results of these t-tests and the effect sizes (unstandardized post-pre mean differences) with 95% confidence intervals are displayed in Table 2 (see Cumming, 2014). There were significant decrements in A' only for the Continuous, and letter detection conditions. The rest condition significantly improved.

4.2. Response time

For the pre-interruption and post-interruption blocks mean correct response times (ms) were recorded for each participant. The means and standard deviations of response time are presented in Table 2. We employed a 3 (interruption condition) by 2 (block: pre-interruption vs. post-interruption) mixed analysis of variance. Response time significantly increased from pre-interruption (M = 498 ms) to post-interruption (M = 538 ms), F(1,

Table 1
The experimental design for experiments 1 and 2.

Group	Practice 1	Practice 2	Pre-interrupt		Interruption	Post-interrupt
			Block 1	Block 2		
Experiment 1						
Rest	Location detection	Letter detection	Location detection	Location detection	Time countdown	Location detection
Continuous	Location detection	Letter detection	Location detection	Location detection	Location detection	Location detection
Letter detection	Location detection	Letter detection	Location detection	Location detection	Letter detection	Location detection
Experiment 2						
Rest	Location detection	Letter detection	Location detection	Location detection	Time countdown	Location detection
Continuous	Location detection	Letter detection	Location detection	Location detection	Location detection	Location detection
Letter detection	Location detection	Letter detection	Location detection	Location detection	Letter detection	Location detection
Verbal memory	Location detection	Verbal memory	Location detection	Location detection	Verbal memory	Location detection
Spatial memory	Location detection	Spatial memory	Location detection	Location detection	Spatial memory	Location detection

Note: In experiment 1 the blocks are .88 min whereas in experiment 2 the blocks are 1.76 min. The interruptions in both experiments were 1.76 min.

Table 2
Statistical results pre versus post interruption for the three conditions.

Condition	N	Pre-	Post-	t	p	$M_{difference}$	95% Confidence interval	
							Lower	Upper
A′								
Rest	90	0.915	0.931	2.08	.040	0.016	0.001	0.031
		0.093	*0.072*					
Letter detection	84	0.910	0.886	2.76	.007	−0.024	−0.042	−0.007
		0.116	*0.112*					
Continuous	92	0.908	0.883	2.90	.005	−0.025	−0.042	−0.008
		0.083	*0.083*					
Response time (ms)								
Rest	90	499.2	517.4	3.15	.002	18.1	6.7	29.6
		50.3	*66.5*					
Letter detection	84	504.9	537.8	4.04	.000	32.9	16.7	49.1
		71.1	*74.5*					
Continuous	92	489.5	559.7	10.85	.000	70.1	57.3	83.0
		55.5	*63.0*					

Standard deviations are in italics.

263) = 105.71, $p < 0.001$, $\eta_p^2 = .29$. There was a significant block by condition interaction, $F(2, 263) = 15.91$, $p < .001$, $\eta_p^2 = 11$. The main effect for interruption condition was statistically insignificant, $F(2, 263) = 2.00$, $p = .14$, $\eta_p^2 = .02$. To further explore this interaction, we performed a one way ANOVA for the pre-interruption block to determine if there were initial condition differences. There was no significant difference between the groups before the interruption, $F(2, 263) = 1.52$, $p = .22$, $\eta_p^2 = .01$. We then performed separate paired *t*-tests comparing the pre-interruption and post- interruption performance for each group. The results of these *t*-tests and effect sizes (unstandardized post-pre mean differences) with 95% confidence intervals are displayed in Table 2. There were significant changes for all conditions; however, the magnitude of the difference was smaller for the rest ($M_{difference}$ = 18.1 ms), in between for letter ($M_{difference}$ = 32.9 ms) and much higher in the continuous condition ($M_{difference}$ = 70.1 ms).

5. Discussion

In experiment 1, a complete rest was significantly better than continuous task demands or a switch to an alpha numeric (letter) vigilance task in regards to the vigilance decrement. Indeed, perceptual sensitivity (A') after the complete rest was significantly elevated in comparison to prior to the rest. In the other two groups, A' numerically declined relative to pre-interruptions levels. In regards to response time, the post-interruption increase in response time after the complete rest (M = 18.1 ms) was reduced in comparison to the letter detection ($M_{difference}$ = 32.9 ms) and continuous (M = 70.1 ms) conditions. The pattern of these findings is in line with expectations from a resource theory account of the decrement.

6. Experiment 2

The findings from experiment 1 while supportive of the role rest breaks have on vigilance performance provided limited information regarding the impact of interruption tasks with differing resource demands on the vigilance decrement. Therefore in experiment 2 we expanded the number of conditions to five interruptions: participants were given a complete rest with timing information, participants performed the primary visuospatial vigilance task continuously, participants completed the alphanumeric vigilance task, participants performed a spatial match to sample task, or participants performed a letter match to sample task. If resource theory is correct, performance following the interruption should be best for rest, worst for continuous, and differentiated for the other interruption groups. Since the verbal match to sample is most distal in processing terms, requiring neither spatial working memory nor the particular resources required to sustain attention on the vigilance task, this interruption condition should show the least impact on the vigilance decrement but not provide the recuperative benefits of rest. This pattern of results would arguably not be expected from an alternative under-load perspective. There is no reason to expect a priori that a complete rest with a numerical countdown or a verbal match to sample task are objectively less monotonous than a spatial match to sample or alternative alpha-numeric signal detection task. Nevertheless, the primary goal of the present work was to explore a resource theory account and to suggest a method which may help resolve the nature of the resources utilized during a sustained attention task. Given the nature of the interruption tasks, a prediction of relative order based on resource theory is rest is best, verbal memory is next (requiring neither spatial working memory nor sustained attention), then spatial memory or letter detection (sharing one primary demand attribute with the visuospatial vigilance task) and finally, continuous performance is worst (total resource demand overlap). If five conditions are numerically ordered based on their impacts on the vigilance decrement, there are 5! possible orders ($5 * 4 * 3 * 2 * 1 = 120$ possible orders). Resource theory predicts 2 of the possible 120 orders.

7. Methods

7.1. Participants

Five hundred and twenty-one (356 female) students ranging in age between 17 and 50 years ($M = 19.6$ years; $SD = 4.7$) served as participants. The study was carried out along principles laid down in the Helsinki Declaration and was approved by the University Human Ethics Committee.

7.2. Experimental design

The present experiment was a 5 interruption task (rest, continuous, letter detection vigil, verbal memory, spatial memory) ×2 block (pre-interruption vs. post-interruption) experimental design. The interruption task was varied between-subjects and block was a within-subjects factor.

7.3. Procedure

As in the case of experiment 1, stimulus presentations and all stimulus and response timing were controlled using E-Prime 2 Professional (Schneider, Eschman, and Zuccolotto, 2002) running on 3.40 GHz Intel i7 2600 PC computers. Stimuli were displayed on 29.5 × 47.2 cm Phillips 225B2 LCD monitors with resolution 1680 × 1050 pixels refreshed at 60 Hz. Screens were positioned at eye height approximately 50 cm from participants whose heads were not restrained. Participants were run in groups of up to 36 at a time with each participant seated at an individual cubicle workstation within a larger computer laboratory.

The primary visuospatial vigilance task was the same as experiment 1. In our experiment 2, however, the blocks were doubled in total length. Thus all participants completed multiple blocks of trials, each block lasting 1.76 min. Between the first two blocks of the visuospatial vigilance task and a subsequent block of the visuospatial task there was an interruption during which one of five kinds of activity took place (see Table 1). Participants were randomly assigned to these five groups with the probability of assignment being $p = .24$ for rest, and $p = .19$ for the other conditions (rest was the focal interruption group). The rest, letter detection, and continuous interruptions were the same as experiment 1. The two additional condition groups completed memory tasks during the interruption. A verbal memory group (verbal memory) viewed 4 upper case letters for 400 ms, and then 1400 ms later were shown a single lower case letter (Smith, Jonides, and Koeppe 1996). The letter stimuli utilized were A, B, E, F, G, H, J, M, N, R, T, and Y. They were required to press the space bar when the lower case letter named one of the 4 studied letters and to make no response when it did not. Finally a spatial memory group (spatial memory) viewed a pattern of three black dots for 400 ms and then 1400 ms later a small circle appeared in the location of one of the dots or elsewhere on the screen (Smith et al., 1996). Participants were instructed to press the spacebar when the circle marked the exact location of a dot and to make no response when it did not.

Prior to the experimental trials all participants first completed instruction and practice trials for the location detection task. Next the rest, continuous and letter detection groups were instructed and given practice with the letter detection task (although only the letter detection group actually completed any letter detection trials during the interruption period). The two memory groups received instruction and practice in their respective tasks. All participants were then informed that they would complete location detection trials but that these may be interrupted by the task they had just practiced, interrupted by a rest, or that they would continue the location detection task without interruption.

8. Results

8.1. Target detection sensitivity

As in experiment 1, we calculated A', a signal detection metric of perceptual sensitivity, from the participant's hit and false alarm rates (see Macmillan and Creelman, 2005). The means for the five groups for each period of watch are displayed in Fig. 1 (error bars are standard errors of the mean). The first question was whether there were any significant condition differences pre-interruption. We therefore employed a 5 (interruption condition) by 2 (period of watch) mixed analysis of variance for the pre-interruption scores. A' declined significantly from period 1 ($M = .900$) to period 2 ($M = .865$), $F(1, 516) = 55.27$, $p < .001$, $\eta_p^2 = .10$. There was no significant period by condition interaction, $F(4, 516) = 2.21$, $p = .07$, $\eta_p^2 = .02$, and there was no significant condition main effect, F(4,

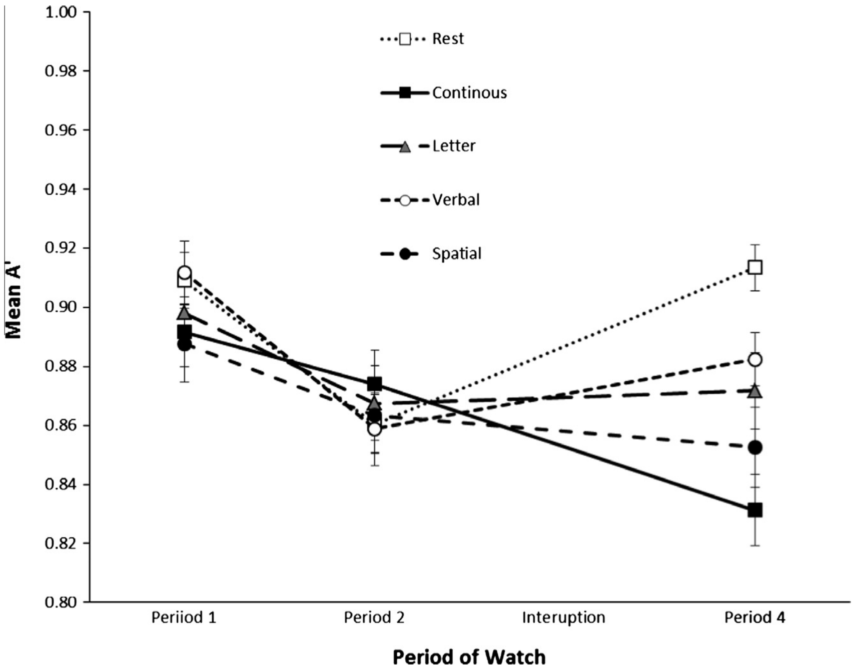

Fig. 1. The mean A' for the five conditions for the periods of watch (error bars are standard errors of the mean).

516) = 0.14, $p = .97$, $\eta_p^2 = .00$. While there was a significant decline in perceptual sensitivity pre-interruption, there were no significant condition differences pre-interruption.

We then performed a 5 (interruption condition) by 2 (period of watch) mixed analysis of variance for the scores on the periods of watch immediately prior to and post the interruption (periods 2 and 4). There was a significant condition by period interaction, $F(4, 516) = 11.18$, $p < .001$, $\eta_p^2 = .08$, but neither main effect was significant: period, $F(1, 516) = 1.17$, $p = .28$, $\eta_p^2 = .00$; interruption, $F(1, 516) = 2.04$, $p = .09$, $\eta_p^2 = .02$. To follow up on the significant interruption by period interaction and in line with our main theoretical intent, we then performed separate paired *t*-tests comparing the pre-interruption and post-interruption performance for each interruption group. The results of these *t*-tests, the effect sizes (unstandardized mean post-pre difference), and 95% confidence intervals of the effects are displayed in Table 3. There was a significant decrement in A' only for the continuous condition and a significant increase in A' only for the rest condition. Also of consideration, however, is the relative rank order of the changes themselves. Given 5 conditions there are 120 possible orders. Resource theory predicts only 2 possible relative orders of the 120: rest is best, then verbal memory, then either spatial memory or letter detection, and finally the continuous task. Indeed the ordered results match one of the a priori predicted patterns ($p = .017$).

8.2. Response time

The mean reaction times for the five groups for each period of watch are displayed in Fig. 2 (error bars are standard errors of the mean). Similar to A', the first question was whether there were any significant condition differences pre-interruption. Note the degrees of freedom for these analyses may differ from those conducted on A' due to exclusion of participants who had no reaction time in a period due to a lack of correct detections. We employed a 5 (interruption condition) ×2 (period of watch) mixed analysis of variance for the pre-interruption means. Reaction times increased significantly from period 1 ($M = 505$ ms) to period 2 ($M = 554$ ms), $F(1, 513) = 350.22$, $p < .001$, $\eta_p^2 = .41$. There was no significant period by interruption group interaction, $F(4, 513) = 0.12$, $p = .98$, $\eta_p^2 = .00$, and there was no significant interruption group main effect, $F(4, 513) = 0.69$, $p = 0.60$, $\eta_p^2 = .01$. While there was significant increase in reaction times pre-interruption, there were no significant between interruption group differences pre-interruption.

We then performed a 5 (interruption condition) by 2 (period of watch) mixed analysis of variance for reaction times for the periods of watch immediately prior to and post the interruption (periods 2 and 4). There was a significant interruption condition by period interaction, $F(4, 513) = 9.09$, $p < .001$, $\eta_p^2 = .07$, a significant main effect for period, $F(1, 513) = 22.86$, $p < .001$, $\eta_p^2 = .04$, and a significant main effect for interruption condition, $F(4, 513) = 2.86$, $p = .02$, $\eta_p^2 = .02$. To follow up on the significant interruption condition by period interaction and in line with our main theoretical intent, we then performed separate paired *t*-tests comparing the pre-interruption and post-interruption performance for each interruption group. The results of these *t*-tests, the effect sizes (mean post-pre difference), and 95% confidence intervals for the effects are displayed in Table 3. There was a significant decrease in reaction times only for the rest condition and

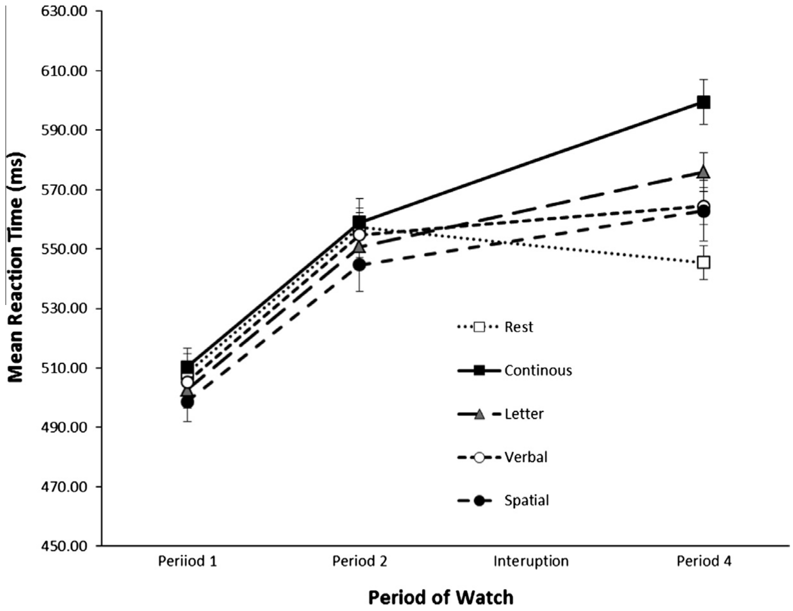

Fig. 2. The mean reaction times (ms) for the five interruption conditions for the periods of watch (error bars are standard errors of the mean).

Table 3
Statistical results pre versus post interruption periods of watch for the five conditions.

Condition	N	Pre-	Post-	*t*	*p*	$M_{difference}$	95% Confidence interval	
							Lower	Upper
A′								
Rest	130	0.860	0.913	2.29	.024	0.053	0.034	0.072
		0.113	*0.090*					
Verbal memory	96	0.859	0.882	1.88	.063	0.024	−0.001	0.049
		0.122	*0.088*					
Letter detection	95	0.867	0.871	0.37	.713	0.004	−0.019	0.027
		0.123	*0.127*					
Spatial memory	91	0.863	0.853	0.88	.381	−0.011	−0.035	0.013
		0.119	*0.129*					
Continuous	109	0.874	0.831	3.77	.000	−0.043	−0.065	−0.020
		0.122	*0.126*					
Response time (ms)								
Rest	130	557.2	545.4	5.55	.000	−11.8	−22.0	−1.6
		76.4	*64.1*					
Verbal memory	96	558.300	562.010	0.42	.676	3.7	−13.8	21.2
		0.101	*0.098*					
Spatial memory	91	544.600	562.900	2.94	.004	18.2	5.9	30.6
		0.068	*0.094*					
Letter detection	93	550.7	575.9	3.63	.000	25.2	11.4	38.9
		71.1	*74.5*					
Continuous	108	558.2	599.1	5.02	.000	40.9	24.7	57.0
		55.5	*63.0*					

Note: The conditions for each performance measure are rank ordered by effect size (unstandardized mean difference).
Standard deviations are in italics.

non-significant change in reaction time for the Verbal condition. As in the case of *A′* also of theoretical importance is the relative order of the changes. Given 5 conditions there are 120 possible orders. Resource theory predicts only 2 possible relative orders of the 120: rest is best, then verbal memory, then either spatial memory or letter detection, and finally the continuous task. Indeed the ordered results match one of the a priori predicted patterns ($p = .017$).

9. Discussion

A complete rest resulted in a significant post break increase in *A′* and a significant post break decrease in reaction time. Continuous visuospatial task performance resulted in significant decrease in *A′* and a significant increase in reaction time. In regards to the other conditions, the results were varied. The verbal match to sample task would be least likely to overlap with the primary visuospatial vigilance task in terms of processing resources; it is neither a spatial memory task nor a vigilance task. This task interruption did result in a nearly significant increase in A' and small insignificant change in reaction time. Perhaps most critical is the relative order of the effects of the interruption conditions on post-interruption performance. Based on resource theory only two possible relative orders can be posited a priori: rest is best, then verbal memory, then either spatial memory or letter detection, and finally the continuous task. An a priori prediction of 2 of a possible 120 relative orders would only occur at $p = .017$, if order were truly random.

10. Overall discussion

There is still active debate regarding the cause of the vigilance decrement (Helton and Warm, 2008). The dominant explanation amongst active vigilance researchers is based on resource theory, but this has been criticized routinely for being circular (Navon, 1984). In addition, resource theory is often mischaracterized; for example, recently it has been considered the same as generalized ego depletion theory (Kurzban et al., 2013). Part of this problem may be due to resource theorists themselves not being clear regarding the specific nature of the information processing resources being depleted and failing to provide stronger tests of resource theory predictions. Here we have demonstrated that distinct and different tasks requiring working memory impair vigilance performance in different ways. Since working memory is a primary system implicated in the vigilance decrement (Parasuraman, 1979), these tasks' disruption of performance in comparison to a complete rest fit with resource theory. This theoretical perspective entails that completely resting the system components of a vigilance task is necessary for full performance recovery. The three interruption tasks of experiment 2, letter detection, verbal memory, and spatial memory are unlikely to overlap entirely with the primary vigilance task in neural resource utilization. Indeed, amongst the three novel interruption tasks, the verbal match to sample is likely to overlap the least with the primary vigilance task. Therefore resource theory for experiment 2 would predict one of two relative orders: rest, verbal memory, spatial memory or letter detection and finally continuous. One of the two a priori predicted relative orders occur for both sensitivity and reaction time.

An alternative perspective may be that the different interruption tasks not only utilize qualitatively distinct resources, but also may differ in the total quantity of resources required. The tasks may have elicited different levels of cognitive load. Parsing apart these possibilities is a goal for future research. Nevertheless, the primary finding, in which a complete rest is best, is supportive of a resource depletion explanation of the vigilance decrement. Either a qualitative difference explanation or a quantitative difference explanation also matches expectations from a resource theory. Indeed Wickens (1976, 2008) himself has always been clear to point out that the multiple resource theory (MRT) account of task performance does not eliminate the role of overall task load. Any resource theory account is not just about the types of resources required, but also about the total amounts required. The vigilance decrement is probably not due to the requirement to simply exert wilful effort on an otherwise unstimulating task (Kurzban et al., 2013) the depletion appears to be contingent on either objective task difficulty, the degree of specific processing overlap or likely, both.

Could alternative under-load theories of the vigilance decrement explain the current results better than resource theory? Many of the alternative theories are based on concepts such as subjective boredom, task monotony, mindlessness, and generalized de-arousal; these theories basically propose the vigilance decrement is due to task under-load (see Hancock, 2013 for a recent review of vigilance). Whether the present results cohere with these alternative theories or not, may depend on how these concepts are construed or interpreted. We, however, find it difficult to understand how a complete rest pause with a clock countdown is more mentally stimulating than performing engaging tasks that have inherently different goals and stimuli (such as the verbal and spatial match to sample tasks). Perhaps, the rest pause allowed participants to engage in day dreaming, which eliminated some task monotony. This perspective, however, does not explain the relative orders of the interruption effects.

While the Letter Detection task is another vigilance task both the verbal match to sample and the spatial match to sample tasks are not vigilance tasks. Both match to sample memory tasks involve non-repetitive stimuli and the continuous encoding and storage of new targets. Nevertheless, the spatial memory task, but not the verbal memory task, resulted in a significant decrement in terms of reaction time and the verbal memory task resulted in a nearly significant post-interruption increase in A'. The primary visuospatial vigilance task and the spatial match to sample task both make use of common spatial memory resources. These specific results, the relative order of the interruption effects, are hard to explain from a purely under-load perspective. Future researchers may want to include thought probes or self-reports of thought states in interruption studies. Unfortunately, one challenge is these probes if embedded into the task may in of themselves trigger off-task thoughts. Alternatively the thought reports could be elicited after the total task is completed, but then would require retrospection which may not be veridical.

Regardless, the present study does suggest a means of more closely examining alternative theories of vigilance by utilizing interruptions of different types during vigilance tasks. While null hypothesis significance testing has received extensive criticism for encouraging weak directionless hypotheses and impairing theoretical development in psychology (Cumming, 2014; Rouder, Speckman, Sun, Morey, and Iverson, 2009), we believe the a priori rank ordering of effects and confirmation of those orders for both performance metrics demonstrates resource theory's relative merits. If a priori relative effect orders are predicted for each theory and enough types of interruptions are utilized, then this provides a powerful test of the respective theories. Relative ordering of effects for interruptions would result in *X*! possible orders (*X* factorial), where *X* is the number of interruption types. For example, if experiment 2 with five conditions were expanded to include another interruption condition which could be rank ordered, then there would be a possible 720 orders. This may provide a simple and useful means to examine the various theories of the vigilance decrement.

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