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Brief article

Brief and rare mental "breaks" keep you focused: Deactivation and reactivation of task goals preempt vigilance decrements

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ABSTRACT

We newly propose that the vigilance decrement occurs because the cognitive control system fails to maintain active the goal of the vigilance task over prolonged periods of time (goal habituation). Further, we hypothesized that momentarily deactivating this goal (via a switch in tasks) would prevent the activation level of the vigilance goal from ever habituating. We asked observers to perform a visual vigilance task while maintaining digits in-memory. When observers retrieved the digits at the end of the vigilance task, their vigilance performance steeply declined over time. However, when observers were asked to sporadically recollect the digits during the vigilance task, the vigilance decrement was averted. Our results present a direct challenge to the pervasive view that vigilance decrements are due to a depletion of attentional resources and provide a tractable mechanism to prevent this insidious phenomenon in everyday life.

1. Introduction

Our ability to maintain a state of focused attention for prolonged periods of time is critical for everyday tasks. Unfortunately, myriad studies have shown that performance on so-called "vigilance" tasks often show a downsloping curve as a function of time (*vigilance decrement*, Davies & Parasuraman, 1982). This decrement of performance over time has been portrayed as reflecting a continuous depletion of attentional resources throughout the vigil (e.g., Davies & Parasuraman, 1982; Helton & Warm, 2008; MacLean et al., 2009). Yet, the nature of these attentional resources that are not being replenished over time remains unclear. Intuitively, it seems like we are always paying attention to *something*; when we disengage from a lecture or a book and start daydreaming, even then we are attending to something: the contents of those dreams, scholarly known as "Task-Unrelated-Thoughts (TUTs)". Recently, researchers have started to study TUTs and shown that they are related to central executive resources (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Smallwood & Schooler, 2006) and attentional capacity (Forster & Lavie, 2009).

Here we propose to examine the vigilance decrement from a different perspective, describing it not in terms of a failure to replenish attentional resources over time, but rather as a failure of cognitive control, also known as executive control (see Miller & Cohen, 2001; Posner & Snyder, 1975), or supervisory attentional system (Shallice, 1988; Stuss, Shallice, Alexander, & Picton, 1995). Braver and colleagues have proposed that maintaining accurate goal representations is a critical component of cognitive control and is required for successful performance in a wide variety of cognitive tasks (Braver & Cohen, 2000; Paxton, Barch, Racinem, & Braver, 2008). They argue that this is because goal representations contain information regarding the actions needed to bring about specific outcomes, which can help guide planning and behavior. According to these authors, these goal representations are maintained in an active online state and are continually able to influence processing.

Within this context of cognitive control, we proposed a new account of the vigilance decrement, stating that the

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cognitive control system may have difficulties in maintaining a goal active for a prolonged period of time (*goal habituation*). Given that all perceptual systems show habituation effects (the diminished and eventual absence of representation to sustained stimulation), and that such effects are observed even when stimuli are actively being attended and used in some cognitive task (e.g., Bonneh, Cooperman, & Sagi, 2001; Troxler, 1804), and further, that habituation effects are observed for even more complex representations like meaning (as in the semantic satiation effect, Lambert & Jakobovits, 1960), here we argued that cognitive goals ought to show similar habituation effects. As such, the activation level of goal representations should gradually decrease over time, making it more likely that, as time goes by, some secondary goal (such as TUTs, or other thoughts that may or may not be related to the vigilance task) may become more active. If so, observers would unintentionally find themselves in a state akin to inattentional blindness, which is known to result in severe decrements in awareness to visual stimuli (Mack & Rock, 1998), even in the context of well-practiced tasks (Strayer & Johnston, 2001). We propose that this form of "goal habituation" is responsible for the deterioration of performance in vigilance tasks. It follows then that if the cognitive control system were able to maintain the task goal active throughout the vigil, then performance would not decline (i.e., there would be no vigilance decrement), in spite of sustained attentional efforts. On this point, we further proposed that momentarily *deactivating* a task goal ought to prevent the vigilance decrement from occurring in the first place because this process would re-strengthen the activation level of the task goal upon resumption of the vigilance task, and thereby preventing it from ever reaching a habituated state. This is somewhat analogous to the way in which perceptual systems avoid (or recover from) states of habituation; small (fixational) eye movements or even brief blinks can easily prevent habituation states from ever arising in vision (Martinez-Conde, Macknik, & Hubel, 2004).

Our "goal habituation" hypothesis appears to be similar to "Mindlessness Theory", put forward by Robertson and colleagues to account for the vigilance decrement (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Mindlessness theory proposes that the vigilance decrement is due to observers' gross inattention or mindlessness. The authors propose that when observers need to perform a monotonous vigilance task, their supervisory attentional system loses its effectiveness and ceases to focus awareness on the vigilance task. At that point, observers are performing their task in a thoughtless manner, via routinization. Although our goal habituation hypothesis resembles mindlessness theory, as both accounts propose that processes that lead awareness to disengage from the task underlie vigilance decrements, our account uniquely identifies "habituation" as a key mechanism responsible for such disengagements. That is, we argue that vigilance decrements ought to be observed for any task that is performed continuously (if goal habituation is allowed to occur), nor should it depend necessarily on the extent to which the task can be routinized.

To test whether goal habituation plays a role in the vigilance decrement and goal reactivation a role in avoiding it, we compared performance in a vigilance task across four groups of observers. One group (Control condition) performed only the vigilance task: detection of shortened lines. Another group (No-switch condition) performed a memory task in addition to the vigilance task. They were required to memorize four digits before the vigilance task, and then were asked to retrieve them upon finishing the vigilance task. A third and critical group (Switch condition) was also asked to memorize four digits, but they were also expected to identify whether a probe digit (sporadically presented during the vigilance session) matched one of the digits in-memory. A final group (Digit-ignored condition) was exposed to the identical stimulus to those used in the Switch condition, but they were only asked to perform the vigilance task. We predicted that the secondary (and rare) task would allow the cognitive control system to momentarily deactivate the vigilance goal (and switch to the memory retrieval task), and further, would comparatively strengthen the vigilance goal upon its reactivation, at the moment when observers resumed the vigilance task. If so, the Switch group should show no vigilance decrement, whereas all other groups should.

2. Method

2.1. Observers

Eighty-four naïve students (37 males) participated.

2.2. Stimuli

One-pixel thick lines were used as stimuli for the vigilance task. The lines subtended 4.5° visual angle vertically, except for targets, which subtended 3.4°. For the memory task, the digits 2–9 were used as stimuli (30-point font size). The lines were displayed in gray (1.31 cd/m^2) and the digits were white on a black background. The fixation point was a red dot, 0.2° in diameter.

2.3. Procedure

On every vigilance trial, either the target or nontarget line was presented at the center of the display for 153 ms, followed by a variable inter-stimulus interval (ISI: M = 1847 ms, *range* = 1353–2341 ms), yielding a rate of 30 events/min (Fig. 1a). The fixation point was continuously visible at the center of the display. Observers' task was to quickly press a key whenever they detected the appearance of the shorter target line. They performed this task for 40-min without breaks, comprising four continuous blocks of 300 trials (10 min): for a total of 1200 trials. Target lines were pseudo-randomly presented on 10% of trials, with the restriction that thirty targets appeared on each block.

2.4. Design

Participants were randomly assigned to one of four conditions.

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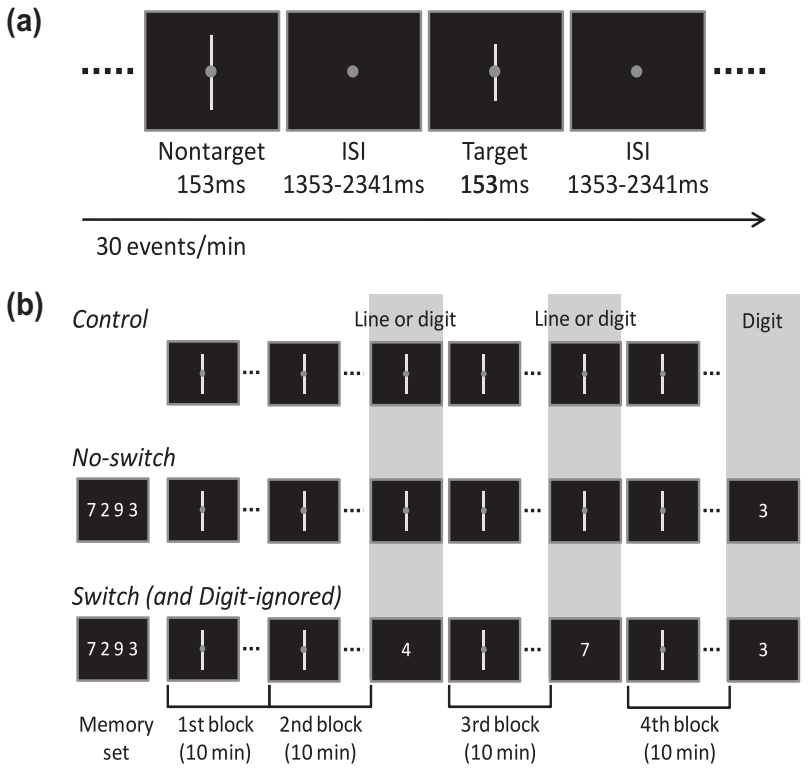

Fig. 1. Example of trial events (a) and schematic design of the experimental conditions (b). All stimuli were displayed on a 21-inch CRT monitor.

2.4.1. Control group (21 participants)

Observers performed only the vigilance task (Fig. 1b-top).

2.4.2. No-switch group (24 participants)

Observers performed a memory task in addition to the vigilance task (Fig. 1b-middle). For this group, a set of four digits were initially presented for 5 s before the vigilance task. Observers were asked to memorize these digits. Following presentation of the digits, the vigilance task started. Memory for these digits was only tested once, at the end of the vigilance task (40 min later). Immediately after the last trial in the vigilance task, a digit was presented at the center of the display for 153 ms. Observers were required to press the key (the same key used in the vigilance task) quickly and accurately if the probe digit was one of the memorized digits. Fifty percent of the time, the probe digit belonged to the in-memory set. Observers were also told at the start of the task that digits could appear in the display at any point during the vigilance task. That said, only one probe digit was ever presented (at the end of the vigilance task).

2.4.3. Switch group (23 participants)

The procedure was almost identical to that in the No-switch condition, except that observers were asked to judge whether occasional digits that were actually presented during the vigilance task belonged to the memory-set (in addition to the digit at the end of the vigilance task, Fig. 1b-bottom). Digits were presented after the 600th, 900th and 1200th trial in the vigilance task. Each digit was presented for 153 ms, followed by a 1847-ms response period.

2.4.4. Digit-ignored group (16 participants)

Observers were exposed to the same stimulus sequence than the Switch condition, but were asked to perform only the vigilance task, ignoring any digits presented during the experiment.

Note that in the Control and No-switch conditions, the presentation of the digit was replaced by an additional vigilance trial (i.e., either a target or a nontarget line was presented after the 600th and 900th trials). All groups performed two 50-trial practice blocks for the vigilance task.

Table 1
Mean hit and false alarm rates (and standard deviations) in Block 1 (%).

	Control	No-switch	Switch	Digit-ignored
Hit	86.5 (11.0)	84.7 (10.8)	87.5 (8.2)	89.5 (8.9)
False alarm	1.3 (2.2)	1.0 (1.6)	0.9 (1.5)	1.3 (1.5)

3. Results

The mean hit and false alarm rates in the initial block were shown in Table 1. The target detection sensitivity (A') was calculated for each condition and each block separately (Fig. 2a). *A* 4 (Condition: Control, No-switch, Switch, and Digit-ignored condition) × 4 (Block: the 1st–4th block) two-way analysis of variance (ANOVA) revealed no significant main effect of Condition [$F(3, 80) = 1.23$, *ns.*], but a significant main effect of Block [$F(3, 240) = 20.33$, $p < .001$]. The interaction between these factors was significant [$F(9, 240) = 1.98$, $p < .05$]. Simple main effects of Block

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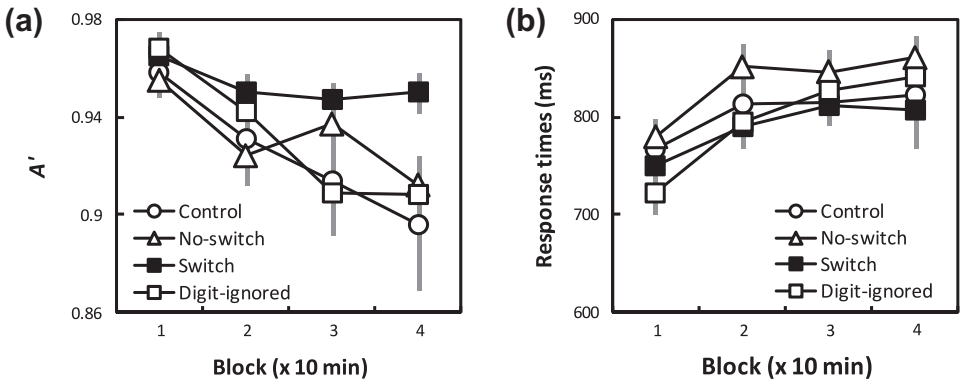

Fig. 2. Mean A' values (a) and response times (b) for each task condition as a function of block. Gray lines represent standard errors of the mean.

were significant for Control, No-switch, and Digit-ignored conditions [$Fs(3, 240) > 4.62$, $p < .005$]. Post-hoc tests (Ryan, 1960) indicated that in the Control and Digit-ignored conditions, sensitivity significantly declined over the 3rd and 4th blocks; and that in the No-switch condition sensitivity declined on the 4th block ($p < .05$). Most crucially, sensitivity in the Switch condition did not decrease as a function of experimental block [$F(3, 240) = 0.89$, *ns.*].[1]

The mean response times for correct detections of the target lines are shown in Fig. 2b. The ANOVA revealed no significant main effect of Condition [$F(3, 80) = 0.88$, *ns.*], and a significant main effect of Block [$F(3, 240) = 23.48$, $p < .001$]. The interaction between these factors was not significant [$F(9, 240) = 0.93$, *ns.*]. Because of extremely low false alarm rates (<1%), response times for false alarms were not analyzed.

One-tailed binomial tests ($\alpha = .05$) were conducted on accuracy rates in the memory task. Performance was significantly above chance (50%) for both memory groups [$z > 1.67$]. Most importantly, there was no difference in overall memory performance between the two groups at the end of the vigilance task [70.8% vs. 69.6% for No-switch and Switch conditions respectively, $\chi^2(1) = 0.05$, *ns.*, two-tailed test]. Further, the Switch group showed somewhat stable levels of memory performance across the vigilance task; 73.9%, 82.6% and 69.6% after the, 2nd, 3rd and 4th block, respectively.

4. Discussion

Here, we proposed that the vigilance decrement occurs because the cognitive control system cannot maintain the same goal representation active over prolonged periods of time (goal habituation). Further, we proposed that temporarily deactivating the vigilance goal would preempt full goal habituation from occurring by re-strengthening the goal's activation level upon resumption of the vigilance task. Our results clearly fall in line with these predictions. When the cognitive control system had to occasionally engage in the memory task during the vigil (Switch condition), observers' perceptual sensitivity remained high throughout the experiment (i.e., no vigilance decrement was observed). In contrast, sensitivity declined over time when the control system was equally loaded with memory information but did not have an opportunity to activate the memory-task goal until *after* the end of the vigilance task (No-switch condition).[2] A similar vigilance decrement was also observed in the absence of the memory load (Control condition) even with the identical stimulus sequence (Digit-ignored condition). Furthermore, we observed no effects of experimental condition on response times in the vigilance task, which is good evidence that observers did not have different speed/accuracy trade-offs across conditions.

It is important to note that performance in the vigilance task was fairly well matched across groups in Blocks 1 and 2, and further, that in fact, observers in the Switch and No-switch conditions performed equally well on the first half of the experiment in the vigilance task and had identical levels of performance in the memory task at the end of the experiment. In other words, Switch and No-switch conditions appeared to be very well matched in terms of overall cognitive load (both required identical levels of memory load and same degree of engagement in the vigilance task). Our results then suggest that differences in vigilance performance between these two groups must then be strongly linked to differences in the mental event sequence; whereas in the Switch group observers are directed to disengage (and soon after to re-engage) in the vigilance task twice during the vigil (having two "power" breaks from the vigilance task), observers in No-switch group continuously perform the vigilance task for 40 min with no directed "break".[3] Clearly, no resource-centered theory of vigilance can account for the current pattern of results.

Our results are consistent with previous reports (Fassbender et al., 2006; Manly et al., 2004) showing vigilant

[1] Follow-up ANOVAs that separately compared the Switch condition against the other three indicated that vigilance performance was significantly higher in the Switch condition compared to the other conditions in Block 4 (all *ps* < .05).

[2] The No-switch condition had a delayed vigilance decrement compared to the control group. This is likely because periodic spontaneous rehearsal of the digits may in fact have similar effects on performance as actually asking participants to perform the digit task.

[3] It should be noted that the current data is consistent with a Yerkes–Dodson arousal account if one assumes that the Switch condition may have been more engaging than the others (Yerkes & Dodson, 1908). That said, no evidence was found for effort or difficulty differences across conditions; and, the experimental differences between the Switch and No-Switch conditions were quite minimal.

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attention being enhanced by periodic alerting cues. These cues were non-predictive of target appearance, but were aimed (via experimental instructions) at reminding participants to concentrate on the vigilance task. Our results demonstrated that attention in a vigilance task can be enhanced even without an explicit instruction linking certain signals (like our digits) to task performance. In fact, we showed that the mere prompt for activating a different task goal (i.e., the memory task) is sufficient to enhance vigilance performance when it resumed. This observation strongly supports our "habituation" hypothesis.

Robertson and colleagues (Manly et al., 1999; Robertson & Garavan, 2004) reported that observers' error responses to to-be ignored stimuli were more often generated when those stimuli were rare than frequent. The authors suggested then that response inhibition provided increased exogenous support for the task through repeated reactivation of the goal representation. Although this explanation and our current model share a similar component (that the level of activation of the goal representation is a key factor in determining vigilance effects), our design revealed that it was neither the target/non-target ratio nor response inhibition that determined performance; rather, the momentarily *deactivation/reactivation* of the vigilance goal plays a much more critical role in averting vigilance decrements. That said, we are currently studying the effect of the target/non-target ratio on vigilance performance in relation to observers' self-report (regarding task difficulty and TUTs). This approach should help constrain our goal habituation model and allow us to investigate what factors trigger goal habituation and study whether task difficulty indeed influences vigilance performance.

In conclusion, we demonstrated that heightened levels of vigilance can be maintained over prolonged periods of time with the use of brief, relatively rare and actively controlled disengagements from the vigilance task. Although it is typically observed that performance always decreases when a second (even very different) task is introduced (Bourke & Duncan, 2005), our results demonstrated that the addition of the second task significantly improved performance in the main task. Our results suggest that deactivation and reactivation of the vigilance goal play a crucial role in vigilance tasks and further, they provide strong evidence against the pervasive view that vigilance decrements are unavoidable and reflect a systematic dwindling of attentional resources that occur as we engage in sustained mental efforts over long periods of time. In sum, vigilance decrements are not about an exhaustion of attention, they are about a loss of control over the contents of our thoughts. Happily, it is a surprisingly easy-to-prevent loss of control.

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