The Effect of Cognitive Switching on Sustained Attention

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Abstract

Tasks requiring sustained attention tend to show a decline in performance over time—a phenomenon known as the vigilance decrement. Recent research has successfully used task switches to reveal more about this decrement, but the analysis of individual switch factors has not yet been explored. In this study, a sample of 37 undergraduate Psychology students performed a fast-paced sustained attention task, containing (a) a stimulus switch, (b) a goal switch, (c) a response switch, or any combination of the three. The habituation model of vigilance predicted that these switches would improve performance, because they would increase arousal and restore attention. Instead, these switches worsened performance, apparently because of task set interference. Also, an interaction between response switching and goal switching was found, consistent with prior research. These results demonstrate the importance of examining the content of a task, and the nature of a switch, as separate factors affecting performance.

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The Effect of Cognitive Switching on Sustained Attention

Sustaining one's attention to repetitive or uninteresting stimuli can be very difficult. We can play games for hours, and watch movies in rapture, but simpler, less exciting activities can have us squirming with boredom. The purpose of this paper is to explain why simple tasks can be difficult in this way, and explore what we can change in our approach, to make these tasks easier to manage.

The ability to sustain one’s attention is critical for a wide range of tasks. During World War II, radar operators relied heavily on this skill as part of their daily work, monitoring radar screens to detect the appearance of enemy submarines (Mackworth, 1948). Today, workers at airport security checkpoints perform a very similar type of task, attempting to detect infrequent threats from a massive amount of disordered stimuli (Hancock & Hart, 2002). In both of these examples, if targets are missed, or reaction time is slow, the consequences may be disastrous. Unfortunately, research consistently shows that performance on these types of tasks declines over time (Mackworth, 1968). This effect has been termed the *vigilance decrement* (Davies & Parasuraman, 1982).

This introduction will review the literature on the vigilance decrement, and attempt to integrate a broader discussion on the properties of attention in general. In doing so, this introduction will explain how early research linked habituation to vigilance, how later studies entered a debate of underload vs. overload, and why the most recent research has attempted to use cognitive switching to mitigate the decrement in performance.

Early Theories of Vigilance

Early research on vigilance centred on long-duration signal detection tasks, much like the radar work of World War II (Mackworth, 1948). Theories on the decrement focused on the repetitive, un-arousing nature of these tasks. Consequently, many researchers attempted to alleviate the decrement by making small changes in task design (e.g. adding extra stimuli, or adding rewards). A review of this research outlines the historical development of research on sustained attention, and provides the basis for the habituation hypothesis found in contemporary literature.

Inhibition Theory

N. H. Mackworth (1948, 1950) explained the vigilance decrement through Pavlovian classical conditioning, identifying inhibition as the primary cause of the decline. Mackworth perceived inhibition to be a basic mechanism of learning, by which unreinforced behaviour is gradually suppressed over time. Thus, he hypothesized that if sufficient reinforcement were added to vigilance tasks, performance would not decline. Indeed, Mackworth found that when participants' correct responses were acknowledged (i.e. reinforced), the decrement was significantly less pronounced (Mackworth, 1948). Further supporting his theory, Mackworth found evidence of spontaneous recovery in many of his experiments (Stroh, 1971), which is another phenomenon closely related to classical conditioning: If participants were given a short period of rest in the middle of their task, their performance upon resuming would be at peak level, reflecting complete and quick recovery of performance. Mackworth explained that the rest period caused inhibition to dissipate, and therefore allowed participants to return to their original, fully responsive state (Mackworth, 1950).

Expectancy Theory

Although there exist further similarities between classical conditioning and vigilance (Broadbent, 1953), Deese (1955) highlighted some important inconsistencies. For example, although a theory focused on inhibition can explain the overall decrement, it cannot explain sudden changes in performance on a trial-by-trial basis. Typical inhibition curves are fairly steady in their decline, whereas the vigilance decrement tends to have fluctuations throughout. Prompted by this realization, Deese proposed a theory based on participant expectancies, suggesting that participants attempt to calculate the probability of a signal on each trial, based on their accumulating experience with the task. Thus, participants exert conscious control over their attention, in a resource-saving manner, to mainly focus on the task when they anticipate the appearance of a signal. The way these expectancies change over the course of a task explains the sometimes sudden changes in performance (Deese, 1955). This hypothesis was supported by experiments showing that the encouragement of inaccurate expectancies (through a misleading practice session, for example), can lead to lower than normal performance on the actual task (Colquhoun & Baddeley, 1964, 1967). Furthermore, it has been shown that when the inter-stimulus-interval is constant and small, and thus easier to predict, stimulus detection improves considerably (Baker, 1959). However, although this theory addresses an important weakness of the inhibition model, it fails to explain why performance even in predictable tasks declines over time (Stroh, 1971). In other words, expectancy theory suffers from the reverse problem of inhibition theory: It can explain fluctuations of response, but cannot explain the overall decrement.

Arousal Theory

The problems of inhibition and expectancy theories led into a focus on arousal, informed in large part by the research of Hebb (1955, 1958). Hebb hypothesized that stimuli do not only guide our actions, but serve an arousal function as well. And, stimuli that do not change, or are too predictable, do not arouse our senses in the way that novel stimuli do. The way to improve performance on vigilance tasks, therefore, is to integrate a greater variety of stimuli into the task

(Stroh, 1971). In other words, the recommendation here is to make the task more exciting, and more unpredictable, in contrast to Deese's (1955) suggestion to make the task more regular, and more predictable. Attempts to alter task predictability by adding superfluous background stimuli have occasionally achieved supportive results (Stroh, 1971; although see Helton, Head, and Russell, 2011), but it is difficult to determine how much of this effect is actually due to arousal. Part of the problem is that there appears to be no consensus on how arousal should be measured, or even on how it should be defined (Davies & Parasuraman, 1982). In terms of the definition, for example, some researchers interpret arousal theory to suggest that faster signal presentation should result in increased arousal (Jerison & Pickett, 1964). Others emphasize that the more frequently a signal is presented, the less novel it becomes, and therefore increased presentation rate should result in lowered arousal (Stroh, 1971). In terms of issues surrounding measurement, electroencephalograph (EEG) activity appears to decline over the span of a vigilance task, reflecting a decline in arousal (Coles & Gale, 1971), but the connection to trial-by-trial performance is not always clear (Davies & Parasuraman, 1982). Measures of skin conductance also reflect a general decline in arousal during vigilance (Davies & Krkovic, 1965), but again the relationship to specific performance has been debated (Parasuraman, Warm, & See, 1998).

Habituation Theory

In order to integrate inhibition, expectancy, and arousal into one unified theory, J. F. Mackworth (1968, 1969) proposed the habituation theory of vigilance. Mackworth's theory had two parts. First, the argument was made that inhibition and expectancy are two basic parts of the same mechanism: neural habituation. Mackworth (1968) asserted that the brain forms models (i.e. expectancies) of what it anticipates it will perceive, and constantly compares those models to perceptual input, to suppress (i.e. inhibit) responses to familiar stimuli in a resource-saving way. This is a mechanism optimized to detect change, so that whenever a novel stimulus is perceived, dishabituation occurs, causing the neural response to be restored to its original level (i.e. spontaneously recover).

The second part of Mackworth's (1968) theory was linking habituation to changes in arousal. As in the original arousal theory, the presentation of an exciting or novel stimulus produces an arousal response, which causes a temporary improvement in performance efficiency (Hebb, 1955). However, Mackworth adds that habituation can occur for virtually any part of the task, including the arousal responses themselves (Mackworth, 1968). Therefore, there are actually two processes of habituation at work: (a) habituation to the background events of the task (which can be disrupted by the occasional target stimulus), and (b) habituation to the target events of the task (which depends on the regularity of those events). This reconfiguration of arousal theory creates a new hypothesis, directly related to trial-by-trial performance: Response potentials evoked by target stimuli should decline in magnitude over the course of the task, and low amplitude responses should correlate to missed signals. Indeed, evidence for both of these effects has been found (Belyavin & Wright, 1987; Siddle, 1972).

Summary and Limitations of Early Theories

The early theories of vigilance, culminating in a habituation hypothesis proposed by Mackworth (1969), present a compelling explanation of the vigilance decrement. A large amount of data has been accounted for, and the final description appears quite strong. However, this has not been without challenge. Supportive evidence was highlighted here, but not all researchers agree that the habituation theory makes for the best frame of analysis (e.g. Parasuraman et al., 1998). Some researchers have even begun to question some of the more fundamental assumptions that these early theories appear to rely on. Mackworth’s (1969) theory assumes that it is the simple, repetitive nature of vigilance tasks that make them so vulnerable to decrement. New research suggests that more engaging tasks can produce the same sort of decline.

Recent Theories of Vigilance

Recent research into the vigilance decrement has experimented with a wide variety of task designs, revealing that increasing the pace and difficulty of typical vigilance tasks can sometimes exacerbate the decline in performance. This discovery has led many researchers to consider underload and overload as competing theories of vigilance. In this new line of research, cognitive resource theories are prominent, but the habituation theory is still important.

SART and the Underload Theory

In an effort to highlight the importance of routinization and automaticity within vigilance tasks, Robertson and colleagues (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) designed the Sustained Attention to Response Task (SART). In the SART, the typical vigilance task is reversed. Normally, participants are asked to respond to rare targets among frequent non-target stimuli; in this new task, the target stimuli are frequent, and the difficulty is in withholding responses to the rare non-targets. This makes for a faster, more perceptually demanding vigilance task, and the resulting decrement in performance may appear within as little as 5 minutes. The researchers explained that the reason this task is able to produce the decrement so quickly is that it encourages routinization. Rather than approach every trial with equal attention, participants occasionally allow an automatic response strategy to take over, thereby providing attention a moment to drift (Robertson et al., 1997). The longer the task goes on, the more frequent the attentional lapses become, as reflected in a gradual increase in the number of errors over the course of the task. This increase in lapses of attention has since been described as the development of a state of mindlessness, during which task-unrelated-thoughts become more and more distracting, and overall engagement with the task declines over time (Manly, Robertson, Galloway, Hawkins, 1998; Smallwood et al., 2004). This represents a significant development in vigilance research, because (a) the vigilance decrement was successfully reproduced in a fast-paced task, and (b) cognitive underload was specifically identified as the cause of the decrement, which most previous research had simply taken for granted.

Cognitive Overload and Resource Theory

Many researchers experimenting with the SART came to challenge the conclusions of Robertson et al. (1997). One such challenge came from Helton and Warm (2008), who showed that participants engaged in the SART do not feel under-loaded. In some SART experiments, participants actually report that their mental workload is quite high (Helton et al., 2005), and measures of stress are significantly increased after the task is completed (Warm, Parasuraman, & Matthews, 2008). This indicates that participants are expending a considerable amount of resources attempting to complete the task, which does not fit well with the concept of mindless withdrawal.

Furthermore, if cognitive underload is the reason for the decrement, then one could expect that increasing load to an optimum level should improve performance. Low-load tasks leave resources available, and tempt distraction from task-irrelevant stimuli (Lavie, 2005). Increasing load to a more appropriate level should reduce this vulnerability, and thus improve performance. Tests of this possibility, however, tend to produce further decrements in performance (Helton & Warm, 2008). For example, if participants are given a memory task that lasts over the course of the vigilance task, the performance decrement is exacerbated both in terms of reaction times and error rates (Helton & Russell, 2011, but see Ariga & Lleras, 2011), particularly if the memory task and the vigilance task require common cognitive processes

(Caggiano & Parasuraman, 2004). This result falls more in line with resource overload than underload. If the task were easy enough to promote routinization and automatic processing, then adding a secondary task would not affect performance, or might even improve it (Schneider & Chein, 2003). The fact that the performance decrement is made worse by adding memory load suggests that the vigilance task requires controlled processing, and is sensitive to increases in task demands (Schneider & Chein, 2003). This is strong evidence for vigilance tasks being an example of resource overload, which is in direct contrast to the conclusions of Robertson et al. (1997).

Dual-Task Loads, and Refinements to Resource Theory

Many researchers have turned to dual-task paradigms to illustrate the vulnerability of the vigilance decrement to cognitive overload. However, adding a secondary task is not always detrimental to performance. Caggiano and Parasuraman (2004) found, for example, that if the vigilance task and concurrent task use different types of working memory (in this case spatial and non-spatial memory), no interference in performance is produced. Similarly, Duncan, Martens, and Ward (1997) found limits to attentional capacity within modalities, but not between them, suggesting that there may be different pools of resources for different cognitive faculties. This is in contrast to the traditional resource model, which suggests that any additional load (beyond optimal capacity) will reduce performance (Lavie, 2005). These results support a multiple resource theory, in which dual-task interference depends crucially on significant overlap between the two tasks being performed. In other words, according to this revision, the vigilance decrement may be worsened by the addition of a secondary task, but only to the extent that the secondary task occupies the same resources as the primary task.

Some dual-task configurations have even been shown to improve performance on vigilance tasks. Manly et al. (2004) found that performance on the SART can be significantly improved by periodically interrupting the participants with a task-disrupting switch in stimuli. In the middle of the SART, Manly et al. presented participants with an auditory cue, which had previously been described to the participants as a reminder to focus on the task. Participants' reaction times were momentarily disrupted after the cue, but performance then rose to peak level, apparently because of a re-established attentive stance toward the task (Manly et al. 2004). Mackworth (1950) attained a similar result, when he found that interrupting participants with an encouraging phone call in the middle of their task could have a lasting restoration effect on performance. The fact that an interruption was beneficial to performance is somewhat surprising. In most cases, interruptions are associated with costs to performance, related to the reconfiguration or reassignment of cognitive resources upon entering and exiting the interruption (Cellier & Eyrolle, 1992). However, Speier, Valacich and Vessey (1999) have observed that interruptions elevate arousal, and contribute to the narrowing of attention. In tasks that require quick, simple decisions, this arousal effect can be beneficial (Speier et al., 1999). Still, before concluding that interruptions are beneficial to vigilance performance, it may also be relevant to consider the modality (see Duncan, Martens, & Ward, 1997) and task-relevance (see Gillie & Broadbent, 1989) of these interruptions. In both Mackworth and Manly et al., the alerting event came from a different modality than the normal stimuli, and furthermore was attached to some task-relevant meaning (i.e. encouragement, or a reminder of what to do). Helton et al. (2011) attempted to replicate the results of Manly et al. using meaningless alerts within the same modality, and found no resulting improvement in performance. This suggests that the effects found by Manly et al. and Mackworth may not have been due to task switching after all, but rather due to explicit encouragement. If cognitive switching is to be linked to an improvement in vigilance performance, stronger evidence will be required.

The Effects of Cognitive Switching, and a Return to Habituation Theory

The effect of cognitive switching on the vigilance decrement was analyzed more closely in an experiment by Ariga and Lleras (2011). In this study, participants were randomly assigned to one of four groups. The first group performed a vigilance task, in which the goal was to monitor a flashing line in the centre of a computer screen, and quickly press a button whenever a smaller line appeared in place of the usual one. The second group performed the same vigilance task, plus a memory task. In this group, participants were given four digits to memorize, which were to be held in memory over the course of the vigilance task, and retrieved at the end. To test the memory of this group, a probe digit was presented on the screen at the end of the experiment, and participants were instructed to press a button if the digit was part of the memorized set. The third group was nearly identical to the second, except that probe digits for the memory task were presented at regular intervals during the vigilance task, forcing the participants to switch back and forth between the two tasks over the course of the experiment. Thus, the third group had the same dual-task load as the second group, plus the burden of periodic cognitive switching. The final group was presented with the same visual stimuli as the third group (with probe digits interrupting the vigilance task), but participants were not given an initial set of digits to memorize, and were instructed to ignore the numbers as they appeared. Thus, the fourth group had a single-task load, with periodic switches in stimuli. A pure resource theory would suggest (a) the two dual-task groups would perform worse than the single-task groups, because of the disadvantages of dual-task load (Schneider & Chein, 2003), and (b) the periodic interruption groups would perform worse than their no-interruption counterparts, because of the disadvantages of switching back and forth between two tasks (Monsell, 2003). However, results showed the opposite: The dual-task periodic-interruption group performed better than any other group in the experiment, apparently demonstrating no vigilance decrement whatsoever (Ariga & Lleras, 2011).

Ariga and Lleras (2011) explained their results by involving a habituation theory similar to that of Mackworth (1968). The authors proposed that the momentary switch essentially acted as a break, wherein participants could momentarily find relief from the vigilance task, and allow their focus to recuperate. Drawing a closer to connection to Mackworth's research, we can interpret the switch as a novel event, which caused dishabituation to occur, and therefore allowed neural responses to be restored to their original level. What makes the result of this experiment unique is that (a) a dual-task condition was directly compared against a dual-task plus switch condition, and (b) unlike the studies of Mackworth (1950) and Manly et al. (2004), participants were never instructed to refocus their energy on the task. It seems as though the beneficial effects occurred as a natural result of the cognitive switch. Ariga and Lleras concluded their paper by stating that all that is required to prevent the vigilance decrement is to occasionally release and re-engage the task goal.

The Ariga and Lleras (2011) study represents a strong application of the habituation hypothesis in a modern experimental setting, but it does not perfectly separate all of the factors of cognitive switching. The experiment contained two switch conditions: a goal-and-stimulus switch (in the third group), and a stimulus-only switch (in the fourth group). According to Mackworth's (1968) definition of habituation, both of these switches should have caused dishabituation. The results showed an effect of the goal-and-stimulus switch, but no effect for the stimulus-only switch. A more important issue is in the authors' designation of goal-switching as the most important factor in producing dishabituation. Goal switching was not examined independently of stimulus switching in this experiment, meaning that it may have specifically been goal-and-stimulus switching together, rather than goal-only switching, that produced the effect. Furthermore, there is yet one more factor of cognitive switching that was not even considered: response switching. Over the course of the experiment's vigilance task, it is reasonable to assume that the participants developed a pattern of response, which due to its repetitive nature, may have also been subject to habituation. Having the participants suddenly break that pattern by not responding (in the single-task switch condition), or by responding in an unusual way (in the dual-task switch condition), may have produced a sizable dishabituation effect. Indeed, there is research to show that goal switching, stimulus switching, and response switching are each independently important in affecting performance in sustained attention tasks.

Goal switching. A goal switch involves a reconfiguration of a task set (i.e. the processes required to accomplish the task), which is usually accompanied by an immediate slowing of response (Gilbert & Shallice, 2002). Experiments with goal switches use bivalent stimuli, allowing the rules of the task to be changed independent of the other parts of the task (Chamberland & Tremblay, 2010). Numbers are an easy choice for bivalent stimuli; the task goal can switch from addition to subtraction, or even from a mathematical operation to a sorting operation, without requiring a change in stimuli, and without requiring the participant to change his or her pattern of response. Braver and Cohen (2000) have shown that the active maintenance of goal-relevant information is crucial to the successful performance of a variety of tasks. If goal representation weakens in strength over the course of a task, performance can be expected to decline. If goal repetition is subject to habituation in vigilance tasks, then a momentary goal switch may cause dishabituation. For these reasons, it is believed that a goal switch alone can feasibly cause an independent change in performance.

Stimulus switching. A stimulus switch involves switching out one set of stimuli for a different set, within the same task (Grange & Houghton, 2010). Like goal switching, stimulus switching can be carried out more or less independently of the other factors of the task. This simply requires that the task rules work with more than one set of stimuli, and furthermore that there be some way to track how responses are mapped to the stimuli (Dreisbach, Goschke, & Haider, 2007). In general, stimulus switching is associated with significant switch costs, characterized primarily as increases in reaction time (Dreisbach, Goschke, & Haider, 2007). Studies on stimulus repetition, on the other hand, show strong priming effects that may improve task performance in certain conditions (Schacter, Wig, & Stevens, 2007). Stimulus repetition is closely related to studies on habituation, in which the repetition of a stimulus is identified as the prototypical precursor to a decline in response (Rankin et al., 2009). If stimuli are allowed to habituate during vigilance tasks, then a momentary switch to a different set of stimuli may cause dishabituation. For these reasons, it is believed that a stimulus switch can also feasibly cause an independent change in performance.

Response switching. A response switch involves reversing the direction of response (i.e. changing “yes” responses to “no” responses) to previously practised stimuli of a task (Koch, Schuch, Vu, & Proctor, 2011). Experiments studying the effect of response switching have typically produced this switch by initially promoting the development of stimulus-response mappings (through a repetitive primary task), and then suddenly making a slight change to the task's rule, causing participants to reconfigure how they should respond (Koch et al., 2011). Response switching experiments have revealed an interesting interaction between response switching and task switching: When the task repeats, response repetition improves performance, but when the task changes, response repetition worsens performance (Rogers & Monsell, 1995; Dyson & Quinlan, 2004). This suggests that responses do not only map onto stimuli, but onto tasks also. In terms of priming and habituation, it has been demonstrated that responses to stimuli are very rapidly learned, and this learning process appears to play a significant role in resource optimization over the course of a task (Dobbins, Schnyer, Verfaellie, & Schacter, 2004). Similar to stimuli, responses are closely examined in studies of habituation, wherein it is suggested that repeated responses are naturally inhibited by resource-saving mechanisms in the brain, and thus dishabituation may be able to cause a response-pattern to be restored to some original level (Rankin et al., 2009). For these reasons, it is believed that a response switch can generate a third independent change in performance.

The Present Study

The present study attempted to reproduce the beneficial effect of a momentary cognitive switch on vigilance (as seen in Ariga & Lleras, 2011) while keeping separate the individual effects of (a) goal switching, (b) stimulus switching, and (c) response switching. A new continuous-performance task was created for this purpose, based on the SART (Robertson et al., 1997) and other sustained attention tasks (principally Dobbins et al., 2004). Participants were given eight 5-minute blocks of rapidly-presented stimulus-question pairs, to which they had to repeatedly respond with button presses. In the middle of each block, there was a momentary change in the task, which represented one of the eight possible combinations of our three switch factors. The individual and combined effects of these factors were examined in an effort to reveal (a) how different degrees of task change affect the recovery of performance, and (b) which factors of cognitive switch are most important for this recovery to occur. Some of the literature suggested that goal switching would be of highest importance, but our thinking was more influenced by the habituation theory, which stated that any dishabituating change should be enough to cause spontaneous recovery of lost performance (Ranker et al., 2009). Indeed, the characteristics of habituation fueled many of our hypotheses. We predicted:

1. Our basic task block, without any switches, would produce an overall decline in performance over time, as measured by an increase in reaction times and/or an increase in errors, because of habituation due to repetition of all 3 factors of the task (goal, stimuli, and response; Rankin et al., 2009).
2. Any cognitive switches implemented at the midway point in our task would reduce any decrement due to habituation (of the switched factors) accumulated up until that point, and produce an overall improvement in performance, because of dishabituation and spontaneous recovery (Rankin et al., 2009).
3. The more switches we implemented, the greater the recovery of performance would be, because the power of an interruption affects the power of dishabituation (Manly et al., 2004).
4. Of relevance to Hypotheses 2 and 3, the effects of switching would be dependent on time. Initially there would be a decline in performance, because of the immediate cost of task switching (Monsell, 2003), but recovery and improvement would emerge soon afterward, because of the lasting effect of dishabituation (Ariga & Lleras, 2011).

As stated before, the connection between vigilance and habituation is not new; it is supported by a substantial body of research, outlined previously by Mackworth (1968), and revitalized recently by Ariga and Lleras (2011). However, using the most recent review of habituation (Rankin et al., 2009), along with the recent contributions of the resource theory

(Lavie, 2005) and cognitive switching (Monsell, 2003), Mackworth's conclusions can be updated, and new testable hypotheses can be drawn. The design of this experiment was specifically aimed at finding support for the habituation hypothesis and separating the factors of cognitive switching, but in general, it was expected that this research would refine our understanding of how cognitive resources work in the brain, and contribute to theories of why performance on sustained attention tasks declines over time.

Method

Participants

Thirty-seven participants (5 male, 32 female, M_{age} = 21.3 years, age range: 18–39 years) were included in the study, recruited from the lower-level undergraduate population of Ryerson Psychology students. The participants were informed of the general purpose of the experiment before it began, but were kept unaware of the content and ordering of the experimental conditions. Five participants were excluded from analysis as their error rate exceeded 20% (more than twice the remaining group average). All participants reported normal or corrected-to-normal vision.

Materials

Participants sat a computer terminal, in the posture and position of their choice, at an optimal viewing distance from the screen (approximately 57 cm). The presentation of stimuli and the logging of responses were managed through PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). There were four possible questions (Natural? Artificial? Large? and Small?), intended to be complementary representations of two basic task goals: natural/artificial categorization, and large/small categorization. There were eight stimuli, drawn from a collection of images gathered by Brady et al. (2008). These were selected based on their recognisability,

Table 1

Stimuli Used in the Experiment

Set	Natural and Small		Artificial and Big	
1				
2				

and on how well they fit with the pre-selected questions. The stimuli were then arranged into two equivalent sets of four images (see Table 1). Within a task block, only one set of stimuli was used at a time. Each set contained two objects that were both natural and small, and two objects that were both artificial and large.

Design

Participants completed 8 blocks of trials, and each block consisted of three parts. The first part was named the “primary task.” This involved one question, which would be repeated on every trial, and a single set of stimuli, which would be presented in random order throughout the task, for a total of 80 trials. The second part of the block was the “break task,” which again involved one question, and one set of stimuli, but only went on for 4 trials. The third part was the “return task,” which was identical to the primary task. The difference in experimental conditions concerned the content of the break task, as it related to the content of the primary (and return) task.

Table 2 illustrates the eight variations of the break task, representing switches of goal, stimulus, response, and every combination of the three. An independent goal switch involved asking for one type of categorization in the primary task (e.g. “Natural?”), and the other type in the secondary task (e.g. “Small?”). Because the stimuli were always either natural and small or artificial and large, the change in goal did not require a change in response, nor a change in stimulus set. The only effect of a goal switch was in forcing the participant to momentarily adopt a different problem-solving process in addressing the stimuli.

Table 2

Switch Presence for the Eight Variations of the Break Task

Condition	Goal Switch?	Stimulus Switch?	Response Switch?
1	Yes	Yes	Yes
2	Yes	Yes	No
3	Yes	No	Yes
4	Yes	No	No
5	No	Yes	Yes
6	No	Yes	No
7	No	No	Yes
8	No	No	No

An independent stimulus switch involved using one stimulus set in the primary task, and the other set in the break task. Because the stimulus sets had categorically equivalent stimuli, the only effect of this switch was in preventing the participant from relying on learned associations between the question and stimuli. A stimulus switch thus required the participant to momentarily release stimulus-question pairings, and re-assess the details of the task.

An independent response switch involved using one version of a question in the primary task, and the complementary version of the question in the secondary task (e.g. “Natural?” switched to “Artificial?”). Because the two questions represented the same basic task goal, this switch independently disrupted stimulus-response mappings established by the participant, without requiring a switch in stimuli or in goals. This type of switch effectively caused participants to re-assess their response strategy, even though neither the task nor the stimuli necessarily changed.

Combined switches were simply additive combinations of goal, stimulus, and response switches. A switch of all three factors, for example, could involve asking “Natural?” in the primary task, with one set of stimuli, and “Large?” in the secondary task, with the other set of stimuli: a goal switch is represented by a change in categorization type (Natural/Large), a stimulus switch is represented by a change in stimulus sets (Set A/Set B), and a response switch is represented by a flip in yes/no criteria (with the initial task demanding “yes” responses to natural/small objects, and the switch task demanding for “yes” responses to artificial/large objects).

Each participant was individually assigned to a randomized layout of the eight experimental conditions. This randomization primarily concerned the order of the blocks that were completed, but the task specific task components (i.e. the goals, stimuli, and responses used in the primary and return tasks) were also randomized, within the individual blocks.

Procedure

The participants were tested in a small room in the Psychology Research and Training Centre, at Ryerson University. Before the experiment began, each participant was instructed on how the task works, and was encouraged to go through a practice run of the task, which used the question and stimuli set of the first block they would complete. After informed consent, demographic information was collected, and the first experimental block was set up. On every trial of the task, the participants saw a one-word question (e.g. “Natural?”) displayed for 500 ms, followed by an image of an object (e.g. a squirrel) for 600 ms, during which time the participant was expected to respond, as quickly and as accurately as possible. Responses were made through a PsyScope response box with three buttons: the button on the right indicated a “Yes” response to a stimulus-question pair, and the button on the left indicated a “No” response to a stimulus-question pair (the button in the middle was for starting a new task block). Following this, there was a 500 ms screen indicating whether or not the response was correct (or too slow). Correct responses were indicated with a green cross, and incorrect responses were indicated with a red cross. If no response was made, the text “!FASTER!” was displayed on screen, to encourage the participant to try harder. A single block took approximately 5 minutes to complete. When the participant finished a block, the experimenter asked if the participant would like to continue right away or take a break. With the approval of the participant, the experimenter prepared the next block, and the process was repeated. This continued until all 8 blocks were completed. At this point, the participant was debriefed, with a simple explanation of the purpose and rationale of the experiment.

Results

Effects of switching

Table 3 provides a summary of participants’ performance on the return task. Both reaction time (RT) and error rate data were analyzed, in separate four-way 2×2×2×4 repeated measures ANOVAs, followed by Tukey’s Honestly Significant Difference (HSD; $p < .05$) tests. The factors considered were stimulus switch (yes, no), response switch (yes, no), goal switch (yes, no), and time (trials 1-20, 21-40, 41-60, and 61-80). Performance prior to the return task was irrelevant with respect to the factors of the present ANOVA and thus was not considered in the analyses.

Table 4 shows the ANOVA summary for RT data. There was only a significant interaction between goal switch and response switch, $p = .046$. This interaction, displayed in Figure 1, indicates that within goal repetition, response switching yielded faster RTs than response repetition. Tukey's HSD test, however, revealed no significant pairwise differences.

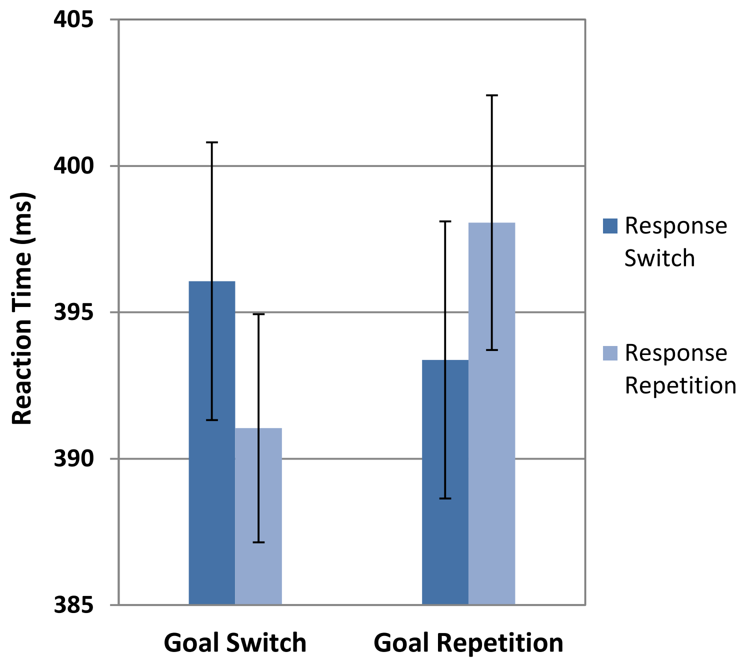

Figure 1. Mean reaction times (in ms) as a factor of response and goal (error bars are standard errors).

In the error rate ANOVAs, displayed in Table 5, there was a main effect of time, $p < .001$, in which the most errors occurred in the trials immediately following a switch (see Figure 2). Tukey's HSD test confirmed that performance on the first set of trials (Trials 1-20) was significantly different from performance on all other sets.

The error rate ANOVAs also revealed near-significant interactions between response switch and time, $p = .064$, as well as between goal switch, response switch, and time, $p = .055$. As shown in Figure 3, within the first 20 trials of the return task, response switch yielded an increase in error rates during goal repetition, but not during goal switch.

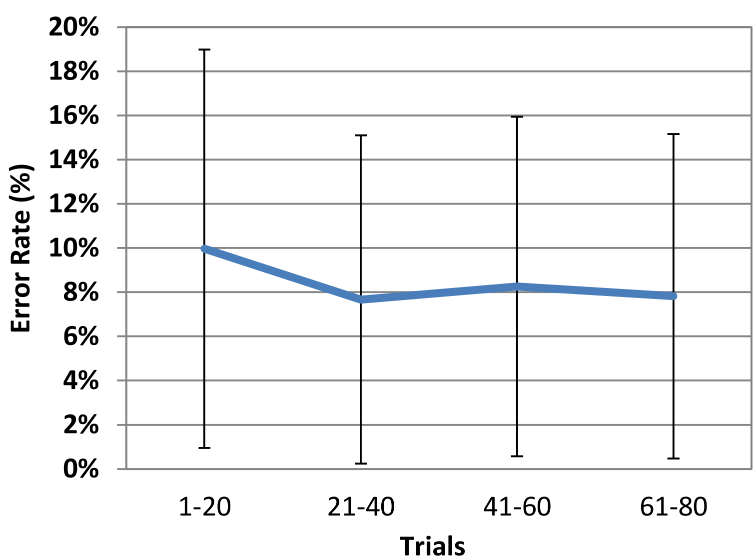

Figure 2. Mean error rate percentages over time (error bars are standard errors).

Lastly, the analysis of error

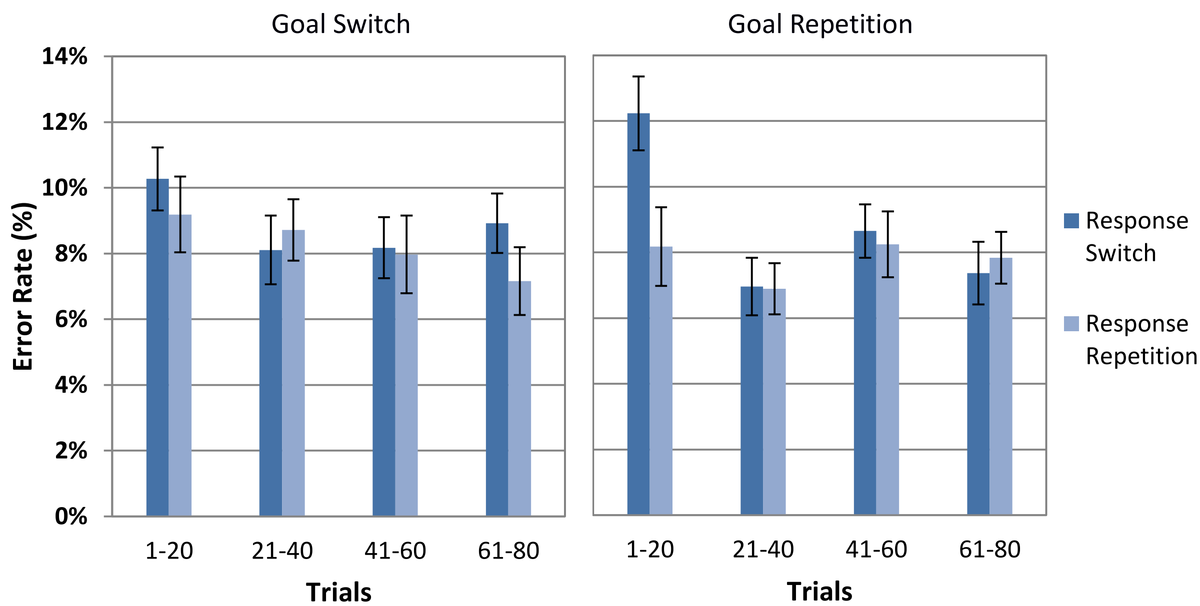

Figure 3. Mean error rate percentages as a factor of goal, response, and time (error bars are standard errors).

rate also hinted at an interaction between stimulus switching and time, p = .090. This interaction, shown in Figure 4, suggests that stimulus switching produced an increase in errors compared to stimulus repetition, but only in trials 41-60. As this interaction did not appear to be meaningful, it was not explored further.

Effects of time

Additional analyses were performed to examine changes in performance across the span of the experiment. These analyses, summarized in Tables 6 and 7 (RTs and error rates, respectively), used a two-way 8×4 repeated-measures design.

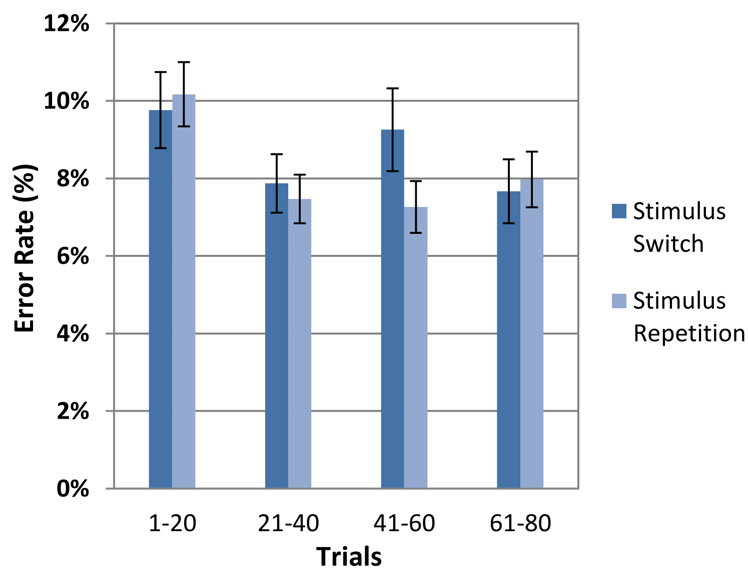

Figure 4. Mean error rate percentages as a factor of stimulus and time (error bars are standard errors).

The factors considered were performance across blocks (1 through 8) and time within block (trials 1-20, 21-40, 41-60, and 61-80; as in the previous analysis). Performance within blocks was already analyzed in more detail with respect to switching (see above), so the main interest here was performance across blocks.

There was a main effect of block, $p = .003$, in which RTs became faster over the span of the experiment. In Tukey's HSD test, block 2 was significantly slower from blocks 7 and 8. The linear trend of the data, $F(1,36) = 10.474$, $p = 0.003$, $\eta^2 = 0.225$, confirmed that participants were slow in the beginning, and gradually got faster as the experiment went on (see Figure 5). There was no quadratic or cubic trend.

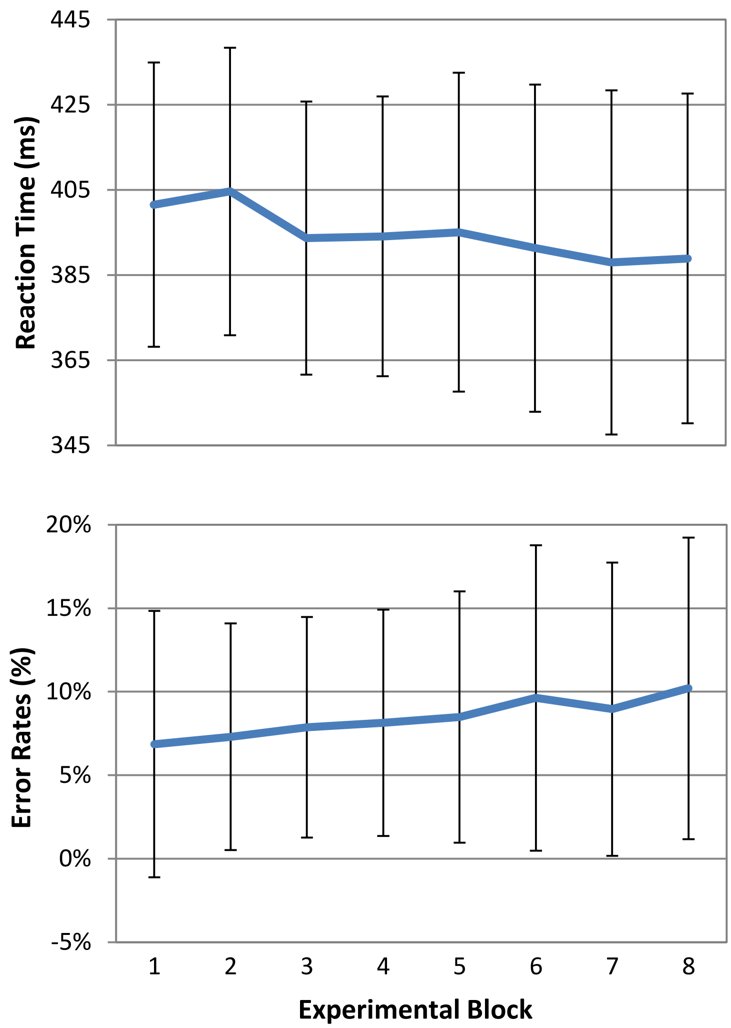

Figure 5. Mean reaction times (in ms) and error rate percentages across blocks (error bars are standard errors).

Block also had a main effect on error rate, $p = 0.038$. Interestingly, considering RTs were shown to improve over time, error rates appear to have steadily worsened over the course of the experiment. Tukey's HSD confirmed that performance on block 1 was significantly different from performance on block 8, and a linear trend in the data, $F(1,36) = 10.055$, $p = .003$, $\eta^2 = .218$, supported the interpretation of a gradual decline (there was no quadratic or cubic trend). Thus, although participants were gradually spending less time per trial, they were also making more errors as time went on (see Figure 5).

Table 3

Summary of Reaction Times and Error Percentages on the Return Task

	RT in milliseconds (SD)				% Error (SD)			
Condition	Trials 1-20	Trials 21-40	Trials 41-60	Trials 61-80	Trials 1-20	Trials 21-40	Trials 41-60	Trials 61-80
YYY	401 (41)	394 (33)	390 (33)	401 (35)	9.59 (8.69)	9.32 (9.44)	9.46 (7.34)	8.92 (7.47)
YYN	391 (39)	391 (41)	386 (39)	391 (31)	9.19 (9.90)	8.1 (7.94)	8.38 (10.14)	7.57 (10.04)
YNY	395 (36)	393 (39)	393 (31)	395 (32)	11.22 (9.31)	6.22 (7.40)	9.59 (8.69)	7.16 (9.44)
YNN	406 (31)	397 (38)	399 (39)	400 (36)	9.05 (12.01)	7.84 (7.41)	9.59 (8.93)	7.03 (6.18)
NYY	394 (40)	397 (38)	399 (37)	392 (38)	10.95 (8.15)	6.89 (6.60)	6.89 (7.30)	8.92 (6.14)
NYN	398 (47)	391 (47)	391 (33)	391 (37)	9.19 (7.50)	9.32 (7.83)	7.57 (6.41)	6.76 (6.03)
NNY	393 (42)	394 (32)	390 (32)	395 (35)	13.24 (8.91)	7.70 (6.52)	7.70 (6.19)	7.57 (8.05)
NNN	397 (35)	392 (31)	392 (35)	400 (33)	7.30 (6.08)	5.95 (5.63)	6.89 (7.20)	8.65 (7.13)

Note. Condition names indicate the presence (Y/N) of stimulus switch, task switch, and response switch, respectively.

Table 4

Summary of Four-Way Repeated Measures ANOVAs for Reaction Time Data

Source	*df*	*MSE*	*F*	*p*	η^2
Stimulus (S)	1, 36	406.043	0.239	0.628	0.007
Task (T)	1, 36	1387.286	0.842	0.365	0.023
Response (R)	1, 36	7.920	0.009	0.924	0.000
Time (X)	3, 108	1178.568	1.874	0.138	0.049
S * T	1, 36	1224.101	0.602	0.443	0.016
S * R	1, 36	4.142	0.002	0.967	<0.001
T * R	**1, 36**	**6967.674**	**4.266**	**0.046**	**0.106**
S * T * R	1, 36	1331.368	0.86	0.360	0.023
S * X	3, 108	187.573	0.358	0.783	0.010
T * X	3, 108	124.774	0.319	0.811	0.009
S * T * X	3, 108	846.524	2.14	0.099	0.056
R * X	3, 108	216.741	0.55	0.649	0.015
S * R * X	3, 108	410.597	0.827	0.482	0.022
T * R * X	3, 108	107.070	0.205	0.893	0.006
S * T * R * X	3, 108	390.713	0.672	0.571	0.018

Note: ANOVA = analysis of variance. Significant terms in bold.

Table 5

Summary of Four-Way Repeated Measures ANOVAs for Error Rate Data

Source	*df*	*MSE*	*F*	*p*	η^2
Stimulus (S)	1, 36	0.005	0.360	0.552	0.010
Task (T)	1, 36	0.002	0.313	0.579	0.008
Response (R)	1, 36	0.019	1.394	0.245	0.036
Time (X)	**3, 108**	**0.033**	**8.343**	**<0.001**	**0.188**
S * T	1, 36	0.000	0.039	0.844	0.001
S * R	1, 36	0.001	0.140	0.711	0.004
T * R	1, 36	0.001	0.179	0.675	0.005
S * T * R	1, 36	0.011	1.900	0.177	0.050
*S * X*	*3, 108*	*0.009*	*2.309*	*0.090*	*0.060*
T * X	3, 108	0.006	1.597	0.194	0.042
S * T * X	3, 108	0.002	0.440	0.725	0.012
*R * X*	*3,* 108	*0.011*	*2.496*	*0.064*	*0.065*
S * R * X	3, 108	0.004	0.866	0.461	0.023
*T * R * X*	*3,* 108	*0.008*	*2.616*	*0.055*	*0.068*
S * T * R * X	3, 108	0.006	1.679	0.176	0.045

Note: ANOVA = analysis of variance. Significant terms in bold. Trending terms in italics.

Table 6

Summary of Two-Way Repeated Measures ANOVAs for Reaction Time Data

Source	*df*	*MSE*	*F*	*p*	η^2
Block	**7, 252**	**5014.441**	**3.17**	**0.003**	**0.081**
Time	3, 108	1178.568	1.874	0.138	0.049
Block * Time	21, 756	296.938	0.628	0.900	0.017

Note: ANOVA = analysis of variance. Significant terms in bold.

Table 7

Summary of Two-Way Repeated Measures ANOVAs for Error Rate Data

Source	*df*	*MSE*	*F*	*p*	η^2
Block	**7, 252**	**0.019**	**2.168**	**0.038**	**0.057**
Time	**3, 108**	**0.033**	**8.343**	**<0.001**	**0.188**
Block * Time	21, 756	0.004	1.131	0.308	0.030

Note: ANOVA = analysis of variance. Significant terms in bold.

Discussion

The purpose of this experiment was to find new support for the habituation theory in the vigilance debate. Based on the results of Ariga and Lleras (2011), it was predicted that a cognitive switch placed in the middle of a vigilance task would cause performance to improve. Support for this hypothesis was not found. Instead, switching was associated with significant costs to performance, particularly in terms of error rate. Although contrary to our main hypothesis, this finding is consistent with the results of Monsell (2003) and Lavie (2005), and supports the idea that vigilance performance has close ties to cognitive load.

We were first of all interested in seeing whether and how the vigilance decrement was expressed within our experimental task. In this theme, block analyses revealed a speed/accuracy trade-off in performance typical of cognitive fatigue (Gonzalez, Best, Healy, Kole, Bourne, 2010). As participants progressed through blocks of trials, their reaction times accelerated, and their error rates worsened. In other words, participants' responses became increasingly impulsive, and their accuracy suffered. This result, in light of our unique task design, may contribute to our understanding of how the vigilance decrement works. Previous studies on vigilance have discussed the importance of routinization (Robertson et al., 1997) and impulsivity (Helton, Kern, & Walker, 2011), but only within a Go/No-Go paradigm, particularly when the ratio of “Go” to “No-Go” trials is very high. Go/No-Go tasks (like the SART) use a single input button, which participants must either press (on “Go” trials) or not press (on “No-Go” trials). In the SART, the ratio of “Go” to “No-Go” trials is usually around 9:1. To many researchers, this ratio is a key to explaining the vigilance decrement, because it provokes the development of a motor routine, and encourages mindlessness (Robertson et al., 1997). Our task, in contrast, was a two-choice discrimination task, with a 1:1 ratio between the two choices. Since participants had to alternate between two response buttons in equal proportions, they cannot be said to have developed a routine. And yet, they still showed a decrement across blocks. This contradicts the Robertson (1997) account of the decrement, but fits well with the resource perspective. Attentional control, whether accompanied of routinization or not, requires cognitive resources, which gradually decline in capacity if not given time to recuperate (Helton et al., 2005). Our task demonstrated this by preventing routinization altogether, and still producing a decrement. However, this does not yet settle the question of habituation. According to Ariga and Lleras (2011), habituation does not depend on routinization—only on repetition. Indeed, the factors of our task were highly repetitive across blocks, and could still be said to have produced a habituation effect. Clarification this lies in the analysis of our switches.

Ariga and Lleras (2011) suggested that when task factors are continuously repeated, a sudden change in those factors should prompt a renewal of performance on the task, despite the typical costs of cognitive switching. In the investigation of this hypothesis, our experiment tested the effects of brief switches placed in the middle of our (otherwise repetitive) task. It was hypothesized that the switches would produce two effects: Initially there would be a cost to performance, due to the immediate effect of a switch (Monsell, 2003), and later there would be a benefit, due to the lasting effect dishabituation (Ariga & Lleras, 2011). The results only revealed that the switches worsened performance; no dishabituation benefit was observed. In explaining why our switches were not beneficial, perhaps it is important to consider the differences between our task and the Ariga and Lleras task. Our task could be described as short, high-load task: It lasted only 5 minutes at a time, and required a decision on every trial. Ariga and Lleras, on the other hand, used a long, low-load task: It lasted 40 continuous minutes, and responses were only required on 10% of the trials. Although both types of tasks are assumed to be valid tests of sustained attention (Robertson et al., 1997), it may be that they test the limits of cognition in different ways (Helton et al., 2005). In a long, low-load task, it may be that habituation is a stronger factor than resource decline. In that context, the costs of a switch may be absorbed by the available cognitive resources (Lavie, 2005), and a beneficial dishabituation effect may thus emerge. In a short, high-load task, spare resources may not be available, and the costs of switching may therefore overpower the effects of dishabituation. In this way, the effect of a switch may depend on the cognitive load of the task. Future research in this area will depend on direct comparisons between different task loads, as they relate to the effects of cognitive switching. For example, an experiment that differentially distributes load across time between participants may reveal differences in the extent to which resource costs, versus dishabituation benefits, appear following a switch.

Related to switch costs, the design of this experiment led to an interesting anomaly, causing switch costs to appear even when all three factors of the task repeated, i.e. when no actual switching occurred. Several of our hypotheses implicitly depended on the “no-switch” condition being a baseline condition, distinguishable from the other conditions. Instead, all conditions displayed roughly equal return task performance. This may have been due to the design of the experiment. Since 7 out of 8 conditions contained some form of switching, and the ordering of those conditions was randomized for each participant, participants may have learned to anticipate a switch on each block. Thus, on every block beyond the first, performance may have been subject to participant expectancies, causing errors to rise around the midpoint of the task, independent of the actual switches implemented. This does not compare well to previous studies on dishabituation, wherein the switches were exceedingly rare and unpredictable (Mackworth, 1950; Manly et al., 2004; Ariga & Lleras, 2011). Perhaps some element of surprise is required for a switch to be beneficial. In clarifying this, researchers in the future could manipulate the temporal predictability of a switch, to see how it affects performance (e.g. rather than have the switch trials always begin on Trial 80, set them to begin at a random position between Trials 70-90, and perhaps compare with even wider ranges). A positive effect on habituation, however, would be in contest with the effect on switch costs. Task-switching studies have generally found unpredictability to increase the cost of a switch, by preventing preparation (García-Ogueta, 1993; Nicholson, Karayanidis, Davies, & Michie, 2006). In other words, for unpredictability to be advantageous, the effect on habituation would have to overpower the effect on switch costs. Since switch costs were particularly relevant in our experiment, the positive effect of dishabituation may thus have been thwarted on more than one level: first by the load of our task, and second by the predictability of our switches.

Predictability also affected other results of our experiment, although not so much as to completely obscure them. One such result was the interaction between response switching and goal switching. Response repetition is generally found to benefit performance, except in the case of a goal switch (Rogers & Monsell, 1995). Encouragingly, an interaction between these factors was found in both the reaction time (RT) and the error rate data of our experiment. On closer examination, however, the RT interaction was only another expression of the predictability issue.

The repetition of both factors, seemingly the easiest condition, produced the slowest performance of all—likely a result of caution, in the anticipation of a switch. The error rate interaction, although statistically insignificant, was more informative. Error rate contained a 3-way interaction of goal, response, and time. The time factor indicated that the interaction was limited to the first 20 trials of the return task, implying that the switch effects were relatively short-lasting. The main product of the interaction was that response switch within goal repetition produced an error rate conspicuously higher than response switch within goal switch. The presence of this interaction is noteworthy on its own, but more generally, this result attaches importance to response switching in a context where the factor is often ignored. If the goal/response interaction applies to vigilance in the same way as it does to other tasks, it may require researchers to re-examine the way they study the effects of switching on vigilance.

The Ariga and Lleras (2011) experiment, for example, had only two switch conditions: a goal-and-stimulus switch, and a stimulus-only switch. Thus, goal switching was not really examined independently of stimulus switching, and response switching was ignored altogether. Based on that design, goal switching was designated as the chief factor affecting vigilance performance, and stimulus switching was deemed unimportant. Considering the results of this experiment, perhaps the conclusions offered by Ariga and Lleras need to be redrawn. The goal-and-stimulus switch should perhaps be interpreted as a switch of all three factors. This would make sense in terms of our present results, because response switch within goal switch was determined to be the lowest cost type of switch, and thus the most easily absorbed by available cognitive resources. Therefore, it is still reasonable that it was in this condition that the benefits of dishabituation emerged. The stimulus-only switch, on the other hand, was a switch of stimuli, and a break (not exactly a switch) of both goal and response. Participants were instructed to ignore the switches in stimuli, but the switches made the task impossible, and thus forced participants to pause. The comparison being made, therefore, was between switches and breaks, and apparently, the switches were more effective in restoring performance. Understanding this in terms of cognitive load, and the theory of habituation, has some thought-provoking implications for human factors research.

However, before concluding that switches are more beneficial than actual breaks, it may be worthwhile to re-examine the nature of those switches, especially within the factor of goal. As elaborated by Ariga and Lleras (2011), there are many reasons to believe that the cognitive representation of goals plays an important role in the performance of tasks. The switching of a goal, however, can take many forms. Our experiment switched goals based on content: from one categorization goal to another. The Ariga and Lleras experiment, however, switched cognitive processes: from categorization to memory retrieval. As reported by Chamberland and Tremblay (2010), these switches are not of equal quality. Specifically, Chamberland and Tremblay found that task switching produces substantial costs for categorization tasks, but no costs for memory tasks. This can be explained within the theory of task set interference (Allport & Wylie, 2000). Priming effects created by recently-performed tasks can affect performance on a current task, such that if the two tasks are the same, performance will be facilitated; if the two tasks are in conflict (e.g. using different rules of categorization), performance will be hindered; and if the two tasks are unrelated (e.g. a categorization task and then a memory task), priming does not apply. Thus, just as in dual-task research (e.g. Caggiano & Parasuraman, 2004), the effect of a switch depends on the nature of overlap between the tasks being performed. The present experiment, interpreted in this way, used an inefficient switch, causing conflict between task sets, and resulting in significant costs to performance. The Ariga and Lleras experiment, in contrast, used an efficient switch, wherein task set conflict was minimal, and the costs to performance were insignificant. Within this model, it could even be argued that in the switch used by Ariga and Lleras, the interference effect was positive. Task set activation can last a considerable period of time (Chamberland & Tremblay, 2010): If not suppressed by the switch, the priming effect may have carried through the (2 second) memory task, and thus facilitated the resumption of the main task. These considerations help make sense of the differences between the Ariga and Lleras results and those achieved in the current experiment. Furthermore, this analysis emphasizes the importance of analyzing the content of a task, and the nature of a switch—issues that both experiments may have underestimated.

The broader issues surrounding the vigilance decrement, however, are far from settled. The habituation theory, especially, will require some careful scrutiny in future research. To put the problem simply, the premise of beneficial dishabituation seems to rely on the absence of cognitive load. And, as shown in this experiment, many of the hypothetical mechanisms of dishabituation actually work against the preservation of cognitive resources. These observations may help us refine the habituation theory, by putting some limitations on its scope. First of all, it appears that beneficial dishabituation is only feasible within a very small range of tasks, namely those that are already perceptually easy to perform. This should lead to a re-examination of task pace and cognitive load as they relate to the vigilance decrement, but also to a rephrasing of the habituation theory’s practicality, perhaps away from the idea that switches can reliably act as breaks. Secondly, the analysis of habituation theory’s evidence reveals the difficulty and rarity of achieving a beneficial switch. Task switching, in general, has been abundantly associated with cognitive costs (Monsell, 2003), and adding unpredictability (as this experiment cautiously advocates) may increase those costs even further (Nicholson, Karayanidis, Davies, & Michie, 2006). Additionally, complications with goal/response interactions, task-set interference, and other phenomena illustrate the difficulty of avoiding the costs of a switch. Indeed, the evasion of cognitive costs, and the elicitation of a measurable benefit (as in Ariga & Lleras, 2011), appears to require a very special set of circumstances. As the properties of vigilance become clearer, and as the expressions of the decrement continue to be explored, the delineation of those special circumstances will hopefully improve.

At the very least, the continued exploration of task switching, vigilance, and habituation, will provide a fount of practical knowledge. In terms of informing ideas on productivity, especially related to “multi-tasking,” a number of a number of points can already be made. Overall, it is clear that the effects of dual-task loads, and indeed the effects of task switching, are not consistent across all sorts of tasks. Instead, these phenomena are closely linked to the content of the tasks, and the nature of the switches. In other words, what works in one task paradigm (e.g. low-load long tasks) may not work in another (e.g. high-load short tasks). Benefitting from a task switch, for example, probably requires that the task be relatively low in terms of cognitive load, and that the switch be fairly easy. On that topic, the conclusion can safely be made that achieving efficiency in dual-tasking is dependent on finding tasks that complement one another. If the tasks rely on different cognitive processes (i.e. different modalities, different functions), then they should be compatible (Duncan, Martens, & Ward, 1997; Gillie & Broadbent, 1989; Chamberland & Tremblay, 2010). On the other hand, if the secondary task conflicts with the first task, by requiring a change in a process already in use, then the tasks are probably incompatible, and their grouping will probably yield poor results (as in the current study). In understanding this, the metaphor of cognitive resources is useful: A task switch, for example, will usually harm performance, unless there are sufficient resources to handle the costs (Lavie, 2005). As explained before, however, it is best to view these resources as linked to particular faculties, meaning that although resources may be occupied in one area, they may be free in another (Caggiano & Parasuraman, 2004). In sum, this research contributes in a variety of ways to our understanding of productivity and time management, and demonstrates the broad usefulness of studies in human efficiency.

This study investigated the ways in which cognitive switching affects sustained attention. The results, especially examined in relation to those of Ariga and Lleras (2011), revealed a great deal in terms of the complexities of cognitive load, and the effects of different types of switches. In particular, attention was drawn to the interaction between response switching and goal switching, and a re-interpretation of the Ariga and Lleras study was proposed. Recommendations for future research, and implications for productivity, were also explored, underlining the importance of task content, and the nature of cognitive switching, in affecting performance in vigilance tasks.

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