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Sustained attention failures are primarily due to sustained cognitive load not task monotony

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ABSTRACT

We conducted two studies using a modified sustained attention to response task (SART) to investigate the developmental process of SART performance and the role of cognitive load on performance when the speed-accuracy trade-off is controlled experimentally. In study 1, 23 participants completed the modified SART (target stimuli location was not predictable) and a subjective thought content questionnaire 4 times over the span of 4 weeks. As predicted, the influence of speed-accuracy trade-off was significantly mitigated on the modified SART by having target stimuli occur in unpredictable locations. In study 2, 21 of the 23 participants completed an abridged version of the modified SART with a verbal free-recall memory task. Participants performed significantly worse when completing the verbal memory task and SART concurrently. Overall, the results support a resource theory perspective with concern to errors being a result of limited mental resources and not simply mindlessness per se.

1. Introduction

Sustained attention or vigilance is the ability of an organism to maintain focused attention on a task and respond to the occurrence of rare critical targets (Warm, 1984). The early work of Norman Mackworth established that even highly motivated and trained operators have great difficulty maintaining optimal vigilance over time (Mackworth, 1948). In laboratory settings, vigilance is commonly measured using a Go/No-Go target detection task, whereby participants are required to respond to rare Go targets and withhold to numerous neutral No-Go stimuli. Generally, participants' performance becomes impaired with time-on-task. Lapses in vigilance are measured by errors of omission (non-responses to the target stimuli) and/or unusually slow responses to correct target stimuli (Davies & Tune, 1969).

More recently researchers have begun to utilize other methodological approaches to measure lapses of sustained attention. For example, the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) is often used in experimental and clinical environments to measure lapses in sustained attention (Docktree et al., 2004; Johnson et al., 2007; Manly, Robertson, Galloway, & Hawkins, 1999; Smallwood, Obsonsawin, & Heim, 2003). The SART differs from the traditional formatted vigilance task (TFT) mentioned above by inverting the relative proportion of Go and No-Go responses. Unlike the traditional vigilance task, participants in the SART are required to respond to numerous neutral stimuli and withhold their response to the rare critical targets (Robertson et al., 1997).

Generally, simple numeric stimuli are used in the SART. For example, participants are tasked with withholding responses to a predefined numeric target (e.g., 3) and overtly responding to a larger digit set (e.g., 1, 2, 5, 7, 6, 7, 8, and 9) using a single button response. Lapses of attention in the SART are primarily measured by errors of commission (EC; inappropriately responding to the rare No-Go target). Errors of commission occur very quickly in the SART, within 4 min. The use of the SART has generated theoretical debates regarding the underlying cause of sustained attention lapses and has subsequently resulted in a debate regarding whether the SART is itself an appropriate measure of sustained attention (Carter, Russell, & Helton, 2013; Doneva & De Fockert, 2014; Grahn & Manly, 2012; Jonker, Seli, Cheyne, & Smilek, 2013; Staub,

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Doignon-Camus, Bacon, & Bonnefond, 2014; Staub, Doignon-Camus, Després, & Bonnefond, 2013).

Although there has been decades of research on the topic of vigilance, there is still disagreement with concern to the cognitive mechanisms responsible for causing sustained attention lapses (Ariga & Lleras, 2011; Greene, Bellgrove, Gill, & Robertson, 2009; Helton & Warm, 2008; Rosenberg, Noonan, DeGutis, & Esterman, 2013). Two main theories have been put forth to explain lapses of sustained attention, the mindlessness, boredom, or monotony theories (underload theory) and conversely, mental fatigue or resource expenditure theories (overload theory).

Proponents of mindlessness and boredom theories argue that vigilance tasks are cognitively undemanding and are monotonous. Moreover, it is this monotony that causes participants to withdraw their attention from the task (Robertson et al., 1997). In line with this perspective, most vigilance tasks employed in experimental research, dating from Mackworth's original clock task, have been objectively monotonous in nature (Hancock, 2013; Manly et al., 1999, 2004; Robertson et al., 1997). According to the proponents of the mindlessness-boredom theory, the vigilance decrement is the result of participants becoming bored or entering a mindless state as a result of the objectively monotonous nature of the vigilance task stimuli (Robertson et al., 1997). In other words, a lack of exogenous support of attention causes participants to disengage from the vigilance task and this results in errors. Therefore, according to the mindlessness-boredom theoretical account of sustained attention lapses, performance should significantly improve by reducing the monotony of the task by adding stimuli either to the task directly or to the background environment, thereby providing exogenous attention support into the task environment. Indeed, mindlessness-boredom theorists have argued that including sporadic sounds in addition to the SART has a refocusing effect (Manly et al., 2004). Manly et al. argue that additional stimuli occurring simultaneously with the SART reorients the participants' executive attention system back to the task which enables participants to appropriately withhold to the No-Go signals.

Alternatively, resource theorists argue that maintaining vigilance is cognitively demanding and is thus resource dependent (Head & Helton, 2012, 2013a; Head, Russell, Dorahy, Neumann, & Helton, 2011; Helton, 2009). Consequently, participants' ability to maintain focused attention on a vigilance task is a function of the amount of mental resources available (Helton, 2009; Helton & Warm, 2008; Shaw, Satterfield, Ramirez, & Finomore, 2012; Shaw et al., 2013). Thus, as task time progresses mental resources are depleted more quickly than they are replenished, which is behaviourally manifested as the increasing lapses of attention (performance impairment).

In addition, many resource theorists argue that the SART is not itself a measure of sustained attention, but rather a measure of participants attempting to resolve conflicting task requirements of responding both as fast and as accurately as possible (Peebles & Bothell, 2004). Therefore, resource theorists argue that the SART is a measure of impulsivity, motor control, or response strategy (Carter et al., 2013; Funke et al., 2013; Head & Helton, 2012, 2013a,b; Helton, 2009; Stevenson, Russell, & Helton, 2011). This issue has not been overlooked by mindlessness-boredom theorists and they have also expressed concerns regarding the ability to separate out sustained attention lapses from motor control (inhibition) errors in the SART (Seli, Cheyne, Barton, & Smilek, 2012; Seli, Cheyne, & Smilek, 2012; Seli, Jonker, Cheyne, & Smilek, 2013).

Failures in motor control are likely due to the response requirement of the task (numerous quick button responses rarely interrupted), which generates a pre-potent ballistic motor routine that is difficult to inhibit (Head & Helton, 2012, 2013a,b; Helton & Russell, 2011; Manly et al., 1999; Robertson et al., 1997). Indeed, participants often report that they are fully aware of the No-Go targets; however, they are unable to physically stop their hand from responding to the target (Head & Helton, 2013a; see also Cheyne, Carriere, & Smilek, 2009). Disrupting the pre-potent ballistic routine by having participants strategically slow their responses can mitigate errors of commission on the SART (Peebles & Bothell, 2004). Many of the errors of commission in the SART are likely due to a speed-accuracy trade-off (SATO) and response strategy. There is growing evidence for the motor control or response inhibition interpretation of the SART. As mentioned previously, when the SART is given, participants are instructed to respond as fast and accurately as possible. However, simply requesting participants to either emphasize speed or accuracy has a significant effect on performance (shifting the SATO). For example, manipulating the task instructions on the SART to emphasize participants to respond slower significantly decreases errors of commission (Seli, Cheyne, & Smilek, 2012). Additionally, controlling a participant's rate of response by using an auditory metronome to delay a response significantly improves commission error performance on the SART (Seli, Jonker, Solman, Cheyne, & Smilek, 2013), thus shifting the SATO. Some researchers have suggested trying to remove the SATO effect from the SART statistically (via correlational methods; see Seli, Cheyne, Barton, et al., 2012; Seli, Cheyne, & Smilek, 2012), and thus attempting to remove the contamination of the SATO on the SART as a measure of attention lapses

Alternatively, another way to control the participant's rate of response, and thus reduce the effect of the SATO, is by reformatting the SART to force slower movement times. Head and Helton (2013a) manipulated stimuli location predictability and stimuli acquisition time by employing a modified point and click mouse SART. Stimuli uncertainty was manipulated by presenting a single numeric stimuli in a predictable or unpredictable location within one of four boxes presented in a cross pattern (see Fig. 1 for similar experimental paradigm). In the random location presentation, a single number stimulus was presented at random in one of the four boxes. In the clockwise condition, a single number stimulus was first presented in the top box followed by number stimuli occurring in adjacent boxes in a clockwise direction. Though number stimuli were randomly sampled (1–9), location of occurrence was entirely predictable. With concern to stimuli acquisition (i.e., how stimuli were selected), participants completed a manual selection and automatic selection condition. In the manual selection condition, participants were required to physically move the mouse cursor to the box containing the Go stimulus (e.g., 1–9 except for 8) and withhold responses to No-Go (8). Conversely, in the automatic selection condition, each box containing a number was automatically selected by the computer; however, a physical button response was still required if a Go stimulus was presented.

Modifying how participants select the stimulus had a significant effect on SART performance. When participants were required to make a physical movement to the target (manual selection) errors of commission significantly decreased relative to the automatic selection condition (Head & Helton, 2013a). Head and Helton argue that manipulating the motor component of the SART affords more time for participants to withhold their response to the No-Go stimuli. Additionally, Head and Helton computed correlations between errors of commission and correct response times to Go stimuli in each of the 4 conditions (thus, examining the intersubject SATO). There were statistically significant negative correlations in each condition except in the random manual-select SART.

More recently, Head and Helton (2013b), investigated the developmental process of SART performance using the clockwise (predictable) manual-select SART over 4 weeks (once a week). The clockwise manual-select SART enabled stimuli location to be predictable and thus facilitated greater movement speed-up with practice. Head and Helton predicted that as participants become more skilled at the task it would result in speeded response errors (increased errors of commission). However, if participants were aware of their performance, then they would be able to strategically shift their SATO. Additionally, participants also completed self-report measures of task-related and task-unrelated thoughts every session to determine whether conscious thoughts showed relationships with SART performance.

As predicted, participants generally sped up on the task, resulting in increased commission errors. The participants were, however, strategic and the participants' speed and accuracy performance inversely oscillated over sessions. Correlational analysis showed robust negative correlations between response time and