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Target predictability, sustained attention, and response inhibition

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ABSTRACT

We examined whether the sustained attention to response task is a better measure of response inhibition or sustained attention. Participants performed a number detection task for 37.3 min using either a Sustained Attention to Response Task (SART; high Go low No-Go) or a more traditionally formatted vigilance task (TFT; high No-Go low Go) response format. Participants performed these tasks using either a regular fixed ordered stimuli set (1–9, sequentially repeated), in which the target number appeared predictably, or a random order (1–9, random presentation), in which the target number appeared at random. We utilized functional near infrared spectroscopy (fNIRS) to measure cerebral oxygenation levels in the right and left frontal areas. We also used post-task participant reports of arousal, and conscious thoughts occurring during the tasks. Performance differed for the both response format and target predictability. Greater right than left frontal hemisphere activation occurred in the TFT than the SART with time-on-task. In addition, the SART response format resulted in elevated self-reports of task-related thoughts than the TFT response format. The results suggest the SART, random or fixed ordered, places high response inhibition, not necessarily sustained attention, demands on participants. Elevated levels of task-related thoughts during the SART format condition in comparison to the TFT condition does not appear to be in accord with the claim that the SART induces mindlessness.

1. Introduction

People are often required to scan the environment for prolonged periods of time while attempting to detect infrequently occurring critical events whilst ignoring frequently occurring non-critical events (Hancock & Hart, 2002). Researchers label this process vigilance or sustained attention (Davies & Parasuraman, 1982; Helton & Warm, 2008; Mackworth, 1948; 1950/1961; Warm, 1984). Researchers have primarily investigated vigilance using low Go, high No-Go target detection tasks, in which participants make infrequent responses to rare critical signals and ignore more frequently occurring neutral stimuli (See, Howe, Warm, & Dember, 1995). In these tasks, the primary metrics of interest are changes in performance with time-on-task. Generally, participants make less correct detections with time-on-task (more errors of omission or misses), respond slower to the target stimuli with time-on-task or both. This change in performance with time-on-task is labeled the vigilance decrement (Mackworth, 1948).

The vigilance decrement is typically measured with long duration (>30 min) tasks, utilizing a low Go, high No-Go response format: the traditionally formatted task (TFT). The relatively long testing time, however, made the assessment of sustained attention difficult in performance batteries, for example in neuropsychological assessments, or during brain imaging. While short measures with the traditional response format have been developed (Helton, Dember, Warm, & Matthews, 2000; Helton and Russell, 2011a; Helton and Russell, 2011b; Helton & Warm, 2008; Temple et al., 2000), an alternative approach was developed by Robertson, Manly, Andrade, Baddeley, and Yiend (1997). They proposed the Sustained Attention to Response Task (SART), which reversed the traditional response paradigm of vigilance tasks. In the SART, the participant responds to the more frequent neutral stimuli and withholds responses to the rarer critical or target stimuli. The SART is a high Go, low No-Go, task. Unlike traditionally formatted vigilance tasks in which the focus is on the vigilance decrement, Robertson and colleagues proposed that the errors of commission (inability to withhold to the No-Go target) in the SART are the preferred metric of lapses of sustained attention. Indeed, they have argued the SART is a more sensitive measure of sustained attention than traditionally formatted tasks. In the present study these response formats, the TFT and SART, are compared.

Robertson and colleagues (1997) argued that the continuous motor responding to the high frequency Go stimuli in the SART induced a "mindless" state in the participant. The participant presses repeatedly and this responding becomes automatic. The participant's executive system then disengages from the task and this disengagement results in errors of commission (responses to the No Go targets). Thus, from this perspective, the SART is an extremely

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sensitive measure of sustained attention that does not require long testing periods. Indeed, errors of commission in the SART occur very quickly, within 4 min. The high Go, low No Go response format of the SART, unfortunately, makes distinguishing whether the errors of commission are due to the participant failing to consciously perceive the target stimuli or simply a failure to withhold a pre-potent motor response difficult. The former is traditionally considered a failure of sustained attention, the latter, however, could be considered a failure of response inhibition, a strategic decision (willingness to sacrifice accuracy for speed of response), or a marker of participant impulsivity (Bengson, Mangun, & Mazaheri, 2012; Helton, 2009; Helton, Weil, Middlemiss & Sawers, 2010; Helton et al., 2005; McVay & Kane, 2009; Stevenson, Russell, & Helton, 2011). The participant could be fully consciously aware of the target stimuli, but still be unable to inhibit the pre-potent motor response, either because of a strategic decision to go fast on the task or some other motor-control issue.

Indeed, participants' self-reports of their own experiences during the SART are suggestive of the task primarily tapping response inhibition and/or motor planning–control, not sustained attention. When given the opportunity to choose whether the errors of commission in a modified version of the SART, the response switching task (RST), are due to conscious awareness (the participant's conscious self) or to a motor control failure (their hand), participants attribute the errors to their hands, not to themselves (Cheyne, Carriere, & Smilek, 2009). In this modified version participants make the frequent "Go" responses with one hand, and make the rarer "No-Go" response with their other hand. In this modified version, participants report seeing the targets and being fully aware of them, but being unable to stop their hand from responding (alienation of agency). Participants realize that the commission errors on the RST are being made by an independent motor routine, not by the executive system. Indeed, the method to prevent commission errors in the SART is to actively slow responses, thereby inhibiting the self-assembling feed-forward motor program (Helton, 2009; Seli, Cheyne, & Smilek, 2012).

The SART, thus results, in confusion regarding the nature of the commission errors. This has not gone unrecognized by Robertson and colleagues, who acknowledge the original SART confounds response inhibition and sustained attention (Dockree et al., 2004; O'Connell et al., 2009). While they continue to use and advocate the original SART as a measure of sustained attention (Greene, Bellgrove, Gill, & Robertson, 2009; O'Connor, Robertson & Levine, 2011), they have also developed an alternative format of the SART which they claim more cleanly measures sustained attention. In the original SART ($SART_{random}$), the task entailed the random presentation of numbers 1–9, with the participant withholding to one of the numbers and responding to the others. In the modified SART ($SART_{fixed}$), the numbers 1–9 are sequentially presented in a fixed order (1, 2, 3, 4, 5, 6, 7, 8, 9, 1, 2...) and the task is to respond to all the numbers, except a pre-selected target number. They argue that because in the $SART_{fixed}$ the target stimuli's appearance is entirely predictable within the task, the $SART_{fixed}$ should place less response inhibition demands on the participant than the $SART_{random}$.

Along these lines, in a recent study, O'Connell et al. (2009) had participants perform the $SART_{random}$ and $SART_{fixed}$ while electro-cortical activity was recorded. In the $SART_{fixed}$, late positivity and alpha synchronization distinguished No-Go errors from correct Go responses, whereas in the $SART_{random}$ the No-Go errors were marked by diminished N2–P3 signals. The authors interpreted these electro-cortical differences as evidence for a clean separation between No-Go errors in the SART due to failures of response inhibition (mostly occurring in the $SART_{random}$) and No-Go errors due to failures of sustained attention (mostly occurring in the $SART_{fixed}$).

This could give the impression that the $SART_{fixed}$ is, therefore, a purer measure of sustained attention. Unfortunately in order to get enough No-Go errors in both tasks O'Connell and colleagues had the participants perform the two tasks repeatedly, long enough to get >20 No-Go errors. Because participants make less No-Go errors in the $SART_{fixed}$ than $SART_{random}$ this required the participants to perform the $SART_{fixed}$ many more times (average 14.1 blocks; each block ~4.3 min), than the $SART_{random}$ (average 9.8 blocks). Even with the increase of doing the $SART_{fixed}$, participants still made many more No-Go errors in the $SART_{random}$ than the $SART_{fixed}$. While not a focus of their study, if No-Go errors increase over repeated blocks (with time-on-task), and the No-Go errors were sampled from earlier blocks in the $SART_{random}$ than the $SART_{fixed}$, then it is not entirely surprising that the $SART_{fixed}$ No-Go errors appear to be due more to failures of sustained attention in comparison to $SART_{random}$ No-Go errors. This is because the $SART_{fixed}$ No-Go errors are from later blocks when the vigilance decrement has taken its toll, whereas the $SART_{random}$ are from earlier blocks. Thus, both the $SART_{fixed}$ and $SART_{random}$ in short < 6 min formats (as they are usually used) may not be measures of sustained attention per se. If they are used for longer durations, then they would of course become vigilance tasks (Bonnefond, Doignon-Camus, Touzalin-Chretien, & Dufour, 2010). The development of a ballistic feed-forward motor routine is contingent on pressing repeatedly and this process may be separate from target predictability (Helton et al., 2005). Therefore, whether the $SART_{fixed}$ measures sustained attention or not remains an open question.

The issue of the SART measurement properties is of extreme importance given its prevalence and wide-spread adoption amongst researchers. This is important regarding the topics the SART has been used as a tool to explore, including, but not limited too, affective disorders (Smallwood, O'Connor, Sudbery, & Obonsawin, 2007), attention-deficit/hyperactivity disorder (Dockree et al., 2004; Greene et al., 2009), cognitive impacts of earthquakes (Helton & Head, 2012; Helton, Head, & Kemp, 2011), depression (Farrin, Hull, Unwin, Wykes, & David, 2003), schizophrenia (Chan et al., 2009), traumatic brain injury (Chan, 2001; Chan, 2005; O'Keeffe, Dockree, Moloney, Carton, & Robertson, 2007), and wandering minds (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). But this also has important implications for theories of sustained attention itself. Advocates for the mindlessness model of sustained attention, for example, rely almost entirely on studies using the SART. If the SART turns out to not really be a measure of sustained attention, then it calls into question the mindlessness theory. This has important implications in the real world, where mindlessness theorists would recommend certain interventions (for example, content-free cueing), that alternative perspectives would suggest would not only be unhelpful, but under some circumstances could be dangerous (Helton, Head, & Russell, 2011).

In the present study, we therefore had participants perform the number detection task for 37.3 min using either a Sustained Attention to Response Task (SART; high Go, low No-Go) or a more traditionally formatted task (TFT; high No-Go low Go) response format. Participants performed these tasks using either the fixed ordered version (1–9, sequentially repeated), in which the target number appeared predictably, or the random ordered version (1–9, random presentation), in which the target number appeared at random. The aim of this experiment is to look at and compare results from $SART_{fixed}$ and $SART_{random}$ with low Go TFT equivalents. The TFT tasks presumably do not require response inhibition, so comparing perceptually equivalent TFTs and SARTs, should enable us to partial out the role motor responding plays in both the fixed and random versions of the SART. This enabled us to examine time-on-task effects across both response formats and stimuli regularity formats. It is important to determine how the SART relates to traditionally