Acta Psychologica 183 (2018) 75–84

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Prolonging the response movement inhibits the feed-forward motor program in the sustained attention to response task☆

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ARTICLE INFO

Keywords:
Attention
SART
Sustained attention
Speed–accuracy trade-off
Response inhibition
Mind-wandering

ABSTRACT

Despite widespread use in clinical and experimental contexts, debate continues over whether or not the Sustained Attention to Response Task (SART) successfully measures sustained attention. Altering physical aspects of the response movement required to SART stimuli may help identify whether performance is a better measure of perceptual decoupling, or response strategies and motor inhibition. Participants completed a SART where they had to manually move a mouse cursor to respond to stimuli, and another SART where this extra movement was not required, as in a typical SART. Additionally, stimuli were located at either a close or a far distance away. Commission errors were inversely related to distance in the manual movement condition, as the farther distance led to longer response times which gave participants more time to inhibit prepotent responses and thus prevent commission errors. Self-reported measures of mental demand and fatigue suggested there were no differences in mental demands between the manual and automatic condition; instead the differences were primarily in physical demands. No differences were found for task-unrelated thoughts between the manual and automatic condition. The movement effect combined with participants' subjective reports are evidence for time dependent action stopping, not greater cognitive engagement. These findings support a response strategy perspective as opposed to a perceptual decoupling perspective, and have implications for authors considering using the SART. Applied implications of this research are also discussed.

1. Introduction

The Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, and Yiend, 1997) is a Go/No-Go response task used for measuring sustained attention deficits due to, for example, traumatic brain injury (TBI; Chan, 2001; Dockree et al., 2004; Manly et al., 2004; O'Keeffe, Dockree, and Robertson, 2004; Robertson et al., 1997), ADHD (Bellgrove, Hawi, Gill, and Robertson, 2006; Johnson et al., 2007; Manly et al., 2001; Mullins, Bellgrove, Gill, and Robertson, 2005), depression (Smallwood, O'Connor, Sudbery, and Obonsawin, 2007), and mind-wandering (Christoff, Gordon, Smallwood, Smith, and Schooler, 2009). In the SART, participants respond to frequent 'Go' stimuli and withhold responses to infrequent 'No-Go' stimuli. The primary measures of interest on the SART are errors of commission (failing to withhold to No-Go stimuli), errors of omission (failing to respond to Go stimuli) and response times (RTs) to Go stimuli. In the SART, commission errors and speeded RTs to Go stimuli are considered by many researchers as markers or indicators of lapsing attention. Other researchers dispute the idea that commission errors in the SART are necessarily due to attention lapses and instead note the role of response strategy in the task. The SART is characterized by a speed–accuracy trade-off (Head and Helton, 2014a; Helton, 2009; Helton, Kern, and Walker, 2009; Peebles and Bothell, 2004; Robertson et al., 1997). The high Go, low No-Go nature of the task leads to a high rate of responding; most stimuli are Go stimuli. When the infrequent No-Go stimuli do occur, they interrupt the flow of frequent Go stimuli and participants are often physically unable to withhold their response, and thus make an error of commission due to their emphasis on speed. When Head and Helton (2014b) tested participants over multiple sessions they found that participants' oscillated between emphasizing

☆ This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
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https://doi.org/10.1016/j.actpsy.2018.01.001
Received 10 June 2017; Received in revised form 3 November 2017; Accepted 2 January 2018

speed and accuracy, providing further support for the role of response strategy.

The role of motor response inhibition in the SART has been well-established (Helton, 2009; Seli, Cheyne, and Smilek, 2012) and the creators of the SART have acknowledged the central role of the speed–accuracy trade-off in SART performance (Robertson et al., 1997). However, many authors seem to deemphasize the role of motor inhibition processes. Instead these authors propose that participants in the SART become disengaged from the task, or perceptually decoupled, due to the monotonous nature of the SART stimuli and the task itself. Subjects are from this perspective lulled into an automatic pattern of responding which requires little effort to maintain. Thus, participants speed up their responses when they stop paying attention to the task. Because the participants disengage attention to the task they fail to withhold responses to the No-Go stimuli. This idea of perceptual decoupling of attention from the task is the result of mindlessness (Manly, Robertson, Galloway, and Hawkins, 1999; Robertson et al., 1997) or mind-wandering (Smallwood and Schooler, 2006).

An alternative perspective is that commission errors in the SART are not a reflection of mind-wandering, mindlessness, or losses of sustained attention, but rather the result of choice of response strategy. Peebles and Bothell (2004) presented, for example, an Adaptive Control of Thought-Rational (ACT-R; Anderson and Lebiere, 1998) model which can predict the association between RTs to Go stimuli and commission errors in participants' SART performance. Their model incorporates two competing response strategies, one being encode and 'click' (respond)—which favours response speed over accuracy—and the other being encode and 'check'—which favours accuracy over response speed. The choice of response strategy is dynamic, in that a participant may alternate between strategies depending on which is perceived to be the most effective at any one time. Perceptions of effectiveness are partly based on the participant's history of successes and failures with each strategy over the task. In a high Go, low No-Go task such as the SART, it may make sense to prioritise speed over the ability to withhold responses. In the SART, 89% of trials are Go trials, and so a participant responding more quickly stands to gain a performance benefit of speed 89% of the time. However, they are less likely to be able to withhold the Go response when No-Go stimuli occur (only 11% of the time). This appears to be due to the development of a ballistic feed-forward motor program (Head, Russell, Dorahy, Neumann, and Helton, 2012; Helton et al., 2005). The SART is highly conducive to the development of this motor program, because of the high probability that a trial will require a response (Ramautar, Kok, and Ridderinkhof, 2004) as well as the constant quick pressing which is required of subjects (Doyon, Penhune, and Ungerleider, 2003). Motor programs can be beneficial in that they may make a highly-used response more efficient (e.g., faster and requiring less effort) but in the case of the SART they lead to a high rate of commission errors.

It is plausible that the two differing perspectives are not mutually exclusive. However, when evidence of subjects' thoughts during the SART is considered, the validity of the perceptual decoupling argument appears even less likely. Participants often report increases in tense arousal from before the task to after the task, indicating the task is itself stressful (e.g. Head and Helton, 2012). Furthermore, participants often report increases in task-related thoughts (TRTs) and decreases in task-unrelated thoughts (TUTs; Wilson, Russell, & Helton, 2015). Moreover, there are many anecdotal reports of participants afterwards describing how difficult it was to withhold to No-Go stimuli, and how their hand seemed to develop a mind of its own, known as alienation of agency (Cheyne, Carriere, and Smilek, 2009). Participants are aware of their commission errors 99.1% of the time (McAvinue, O'Keefe, McMackin, and Robertson, 2005). Performance on the SART does not appear to be associated with mindlessness, mind-wandering, or lack of attention to the stimuli. That said, SART performance may index another form of attention, that is, internally directed attention. It is plausible that participants must attend to their own response strategy in order to regulate it and manage the constant trade-off between speed and accuracy throughout the task. This form of attention is probably controlled by the supervisory attention system (Norman and Shallice, 1986). An internally directed form of attention is not the same as externally directed attention (i.e., attention as it is usually considered) however.

SART performance is influenced by a number of factors which support a response strategy explanation of SART performance. Altering the task instructions, to emphasize accuracy over speed, leads participants to slow their speed of responding and to make fewer commission errors (Seli et al., 2012). Thus, the tendency to use the "encode and click" or "encode and check" strategies is influenced by top-down executive control or explicit strategy choice. This supports the idea that SART performance is driven mostly by response strategy, as does the finding that providing warning cues to indicate the arrival of No-Go stimuli in the SART helps to prevent commission errors and mitigates the speed–accuracy trade-off (Finkbeiner, Wilson, Russell, and Helton, 2015; Helton, Head, and Russell, 2011). These warning cues facilitate performance only when they reliably precede a No-go stimulus where they provide the time necessary to inhibit the Go response; there is no incentive to choose an encode and click strategy. Introducing an artificial delay to RT can also decrease commission errors, as shown by Seli, Jonker, Cheyne, and Smilek (2013), who had participants wait for a slightly delayed audible cue before they could make a response following stimuli presentation. A longer response window means there is no advantage of the simple encode and click strategy; there is time to check the stimuli.

Altering the response format, by increasing the time that is required to physically make a response, has also been shown to reduce commission errors. Head and Helton (2013, 2014b) required participants to physically move a mouse cursor towards a target to select it before they were able to perform a typical button-press response. Making the physical response more elaborate and slower resulted in longer RTs, which appeared to allow participants time to inhibit the prepotent motor response and consequently to make fewer commission errors. Whether this result is in fact due to participants having more time to prevent prepotent motor responses is uncertain however. Perhaps the physical component of the additional manual movement simply leads to fewer off-task thoughts or mind-wandering, relative to a typical SART, as might be suggested by proponents of the perceptual decoupling perspective. Additionally, the physical component may not only induce additional physical demand, but extra mental demand as well. According to the perceptual or externally-directed sustained attention explanation, commission errors are the result of boredom or "underload," or in other words, *not enough* mental demand (Robertson et al., 1997). The added physical component could serve to increase exogenous support for the task by grabbing participants' attention (Johnson et al., 2007), which, according to this perspective, could lead to a lower rate of commission errors.

The current experiment, like that of Head and Helton (2013), manipulated both the movement required to make responses to stimuli, as well as the stimuli location. Concerning stimuli acquisition, in one condition—'manual selection'—following the appearance of a Go stimulus participants were required to physically move a mouse cursor to a box containing the stimulus before they could then press the mouse button to make a click response, once the cursor was inside the box. In the other condition—'automatic selection'—no movement of the mouse cursor was required. Instead participants had to simply press the mouse button when a Go stimulus appeared in a box. This is more similar to the response format in a typical SART. The second manipulation concerned the location of stimuli. Stimuli locations were arranged to the left and right of the screen center at near and far distances. This enabled the measurement of the effects of target distance (near vs. far) on commission errors and RT.

Both proponents of the response strategy and the perceptual decoupling perspectives may predict that participants would respond slower to stimuli in the manual selection condition and make fewer