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

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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

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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 errors of commission. The additional physical action of moving the mouse cursor to firstly select the stimulus, before a click response can then be made, should slow participants' responses. From a strategic or motor inhibition view of SART responding, the requirement to make the manual movement should lead to fewer commission errors simply because the motor movement required to respond takes longer, which should give participants more time to inhibit the prepotent motor response. From a perceptual decoupling perspective, the additional manual movement may actually induce greater cognitive engagement than a simple automated button press (click). Thus, advocates of the mindlessness or perceptual decoupling perspective may claim that a reduction in commission errors in a manual selection SART is consistent with their perspective. However, would the need to move a bit farther result in less mindlessness? Granted the need to manually acquire targets may induce greater engagement, but if the time of the movement is itself critical then this suggests the need to manually select is beneficial simply because of the temporal delay. Where the two theories would therefore offer differential predictions concerns the impact of distance on performance.

It was predicted that commission errors would be inversely related to distance in the manual selection condition, but not in the automatic selection condition. Stimuli at the far distance should lead to longer movement times when participants are required to manually move their cursor to the stimuli (see Fitts' Law; Fitts, 1954). Since longer movement times should essentially mean longer RTs, participants should make fewer commission errors, because the longer RTs will provide them with more time to inhibit the feed-forward ballistic motor program and thus withhold responses to No-Go stimuli more often. This is consistent with a simple response inhibition or response strategy perspective of SART performance. There is no reason to expect from a decoupling perspective that a slightly longer movement would itself cause greater perceptual coupling to the stimuli. Regardless this method may help resolve the role of delay in responding itself in SART performance. A movement effect is evidence for time-dependent action stopping, not greater engagement.

In addition, self-reported measures of thoughts were taken. Each participant completed two Go/No-Go response tasks and after each of these, two self-report scales to gauge thoughts and workload. The self-report thought and workload scales were predicted to reflect the additional physical demands of the manual selection condition but yield no differences between the mental demands of the manual versus the automatic selection condition, in line with the response strategy perspective. Advocates of a mindlessness or perceptual decoupling perspective of the SART would more likely predict large differences in self-reported TUTs between the manual and automatic SARTs.

2. Methods

2.1. Participants

Forty-one (27 female, 14 male) students from the University of Canterbury, Christchurch, New Zealand, participated as part of a course laboratory class requirement. They ranged in age between 19 and 30 years (*M* = 21.4, *SD* = 1.8). All participants had normal or corrected to normal vision.

2.2. Materials

Participants were tested in individual workstation cubicles, seated 50 cm in front of Phillips 225B2 LCD computer screens (1680 × 1050 pixels, 60 Hz refresh rate) which were paired with 3.40 GHz Intel i7 2600 PC computers. Stimuli presentation, response accuracy and timing were achieved using E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Screens were mounted at eye level and participants did not have their head movements restrained. All participants completed two different Go/No-Go response tasks that were modified versions of the SART (Robertson et al., 1997). The two SARTS differed in the movement (between-task; manual versus automatic) that participants were required to perform to make responses. For both SARTs, four boxes (each 60 mm × 60 mm), serving as possible locations for the stimuli, were displayed on the screen during the task and were arranged horizontally (see Fig. 1) in the vertical center of the screen. A fixation cross (6 mm × 6 mm) was visible in the center of the screen at the onset of each trial. A second manipulation was present within both of the SARTs: distance (within-task; close versus far). To the immediate left and right of the fixation cross was a ‘close’ box centered 55 mm away and a ‘far’ box centered 150 mm away. On each side the distance between the close and the far box was 95 mm. There were 252 trials in each SART. Go stimuli had a proportion of 0.89 and No-Go stimuli had a proportion of 0.11. Each trial a stimulus appeared in one of the four boxes. In the manual SART, at the onset of each stimulus the fixation cross was replaced with a cross hair (as used by Head and Helton, 2013, 2014a, 2014b), which was similar in shape to the fixation cross (6 mm × 6 mm) except larger (10 mm × 10 mm). The change to the crosshair served as a cue for the participant, indicating that they now had manual control over the cursor or crosshair. It should be noted that this visual change itself could have attracted participants' attention. However, at the same moment that the cross extended a new stimulus was also presented, which is likely to have been the more attention-capturing event for participants. Participants were required to manually shift the crosshair from the central point to a box containing a stimulus that they wished to select. Once the cursor was positioned over a box, the box's borders became bolded (thicker), indicating that it was selected. To complete the response participants were required to click the mouse. Participants were not required to move the cursor after they had made a response; the cursor automatically moved back to the central point at the end of each trial. In the automatic SART, at the onset of each stimulus participants were not required to move the mouse as the box containing the stimulus was instead automatically selected for them (again indicated by the borders becoming bolded). To complete a response in this condition, participants only had to click the mouse button. Mouse movement was disabled in the automatic condition. A Microsoft Wheel Mouse Optical was used to move the cursor (manual condition only) and to perform the click (both conditions).

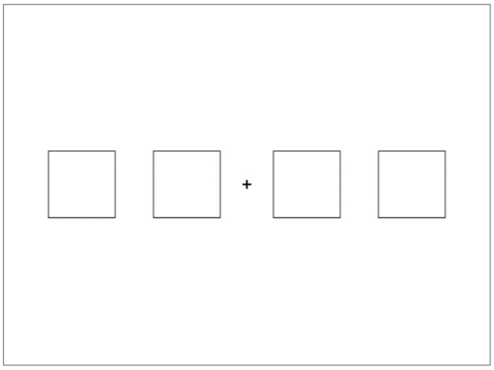

Fig. 1. The four possible stimuli locations and the central fixation cross.

Two self-report questionnaires were used. One was the 11 item Stress Scale (see Blakely, 2014; de Joux, Wilson, Russell, Finkbeiner, and Helton, 2017) where each item was based on factors from the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 2002). Note that the Stress Scale questions are different from those found in the DSSQ. For instance, to gain a measure of TUT in the current study, rather than being a combination of highly specific types of TUTs, there was just one question: “Overall, how much did you think about something other than the task?” Items were ranked on a Likert scale of 0 (“very low”) to 10 (“very high”) and included: physical fatigue, mental fatigue, tense, unhappy, motivation, task interest, self-related thoughts, concentration, confidence, TRTs, and TUTs. The second scale was a

Fig. 2. The computer generated robot images used as stimuli: XM1219 Armed Robotoc Vehicle (left; http://en.wikipedia.org/wiki/XM1219_Armed_Robotic_Vehicle) and Legged Squad Support System (right; http://it.wikipedia.org/wiki/Legged_Squad_Support_System).

modified version of the NASA–Task Load Index (TLX) scale (Hart and Staveland, 1988) used to gauge subjective workload. This version was determined via prior factor analyses (see Bailey and Thompson, 2001; Ramiro, Valdehita, Lourdes, and Moreno, 2010) and consisted of the following six subscales: mental demand, physical demand, temporal demand, performance monitoring demand, effort and emotional demand (see Blakely, 2014; de Joux et al., 2017; Hancock, 2015; Sellers, Helton, Näswall, Funke, and Knott, 2014). Items were ranked on the same 0 to 10 Likert scale used for the Stress Scale. A global workload measure, which was the combined average of the responses to the NASA-TLX subscales, was also computed for each participant.

Stimuli were two computer-generated images of robots (see Fig. 2) sized approximately 85 mm × 85 mm. One was an XM1219 Armed Robotoc Vehicle and the other was a Legged Squad Support System. These were sized to fit inside the boxes and so shared the same dimensions as the boxes. Images were used instead of numbers in an attempt to provide more realism necessary for the application of the task to Shoot/No shoot tasks (see Wilson, Head, de Joux, Finkbneiner, & Helton, 2015) and to encourage participant engagement (see Szalma, Schmidt, Teo, and Hancock, 2014), although it should be noted that any such effect would likely be minor. Through random assignment, half of participants had the XM1219 Armed Robotoc Vehicle as a Go stimulus and the Legged Squad Support System as a No-Go stimulus (for both SARTs), while this allocation was reversed for the other half of participants. Participants' allocation was the same for both SARTs to avoid any possible confusion of swapping stimuli. The order of stimulus presentation was random, as was the location that stimuli appeared in. For each SART, the 252 trials were divided evenly between the four boxes/locations (63 presentations each; 126 at the close distance and 126 at the far distance). Go and No-Go trials were also divided evenly between the locations.

The behavioural metrics of particular interest were errors of commission (failures to withhold to No-Go stimuli), errors of omission (failures to respond to Go stimuli) and RTs to Go stimuli. Cursor movements in the manual condition were also tracked by recording the X and Y co-ordinates of the mouse cursor every 20 ms.

2.3. Procedure

Participants were seated at individual cubicles and asked to switch mobile phones off and to remove wrist watches. They were instructed to respond to Go stimuli ($p = 0.89$) and to not respond to No-Go stimuli ($p = 0.11$). Participants were told to place equal emphasis on speed and accuracy. Before each SART participants were informed which type of robot their Go stimulus was and which type their No-Go stimulus was. They were then told whether the forthcoming SART required manual movement of the mouse or not. For the manual condition, participants were instructed to respond to Go stimuli by moving the mouse cursor or crosshair towards and into the box that the Go stimulus appeared in and then to click the mouse button. For the automatic condition, participants were instructed to respond to Go stimuli by simply clicking the mouse button when Go stimuli appeared. Participants completed a practice task before each SART consisting of 36 trials in the same movement mode (manual or automatic) as their forthcoming SART and containing verbal accuracy feedback.

For both SARTs, each trial began with the four empty boxes and a fixation cross, which lasted for 200 ms, at which point a stimulus then appeared in one of the four boxes. This stimulus was visible for 250 ms. When the stimulus disappeared the four boxes remained on the screen for a further 1000 ms. Thus the total onset to onset interval was 1450 ms. Responses were recorded up to 1000 ms after stimulus onset.

Through random assignment, half of participants completed the manual SART first while the other half completed the automatic SART first. Participants completed the Stress Scale and the modified NASA-TLX scale immediately after each SART. The SARTs were each 6.1 min in duration and the whole experimental session took approximately 20 min to complete.

3. Results

3.1. SART performance

For each subject in each condition, manual and automatic (selection) and close or far (distance) we calculated the proportion of commission errors, proportion of omission errors, and the mean correct Go-stimuli RTs. These data are present in Table 1.

To explore the differences between the conditions, separate 2 (selection: manual vs. automatic) × 2 (distance: close vs. far) repeated measures ANOVAs were performed on each of the three performance measures. These were followed up with paired *t*-tests when necessary, with Holm-Bonferroni corrections (Holm, 1979) used to control the familywise error rate. This procedure is more powerful than the Bonferroni procedure yet maintains the Type I error rate (Park, Cho, and Ki, 2009).

For RTs, there was a main effect of selection, wherein the manual ($M = 560.6$ ms, $SD = 58.2$) selection condition was significantly slower than the automatic ($M = 341.2$ ms, $SD = 40.5$) selection condition, $F(1, 40) = 601.5$, $p < 0.001$, $\eta_p^2 = 0.938$. There was also a main effect of distance, with responses to far ($M = 489.6$ ms, $SD = 43.7$) distance significantly slower than close ($M = 412.2$ ms,

Table 1
SART performance for each condition. Values within parantheses represent standard deviations.

	Automatic		Manual	
	Close	Far	Close	Far
RT (ms)	327.5 (38.3)	354.9 (43.7)	497.0 (58.3)	624.3 (61.4)
Errors of commission	.39 (.22)	.42 (.19)	.05 (.09)	.02 (.05)
Errors of omission	.01 (.02)	.01 (.01)	.01 (.01)	.02 (.02)
Box entries	(NA)		.79 (.16)	.61 (.17)

$SD = 40.2$) distance, $F(1, 40) = 935.5$, $p < 0.001$, $\eta_p^2 = 0.959$. There was also a significant selection x distance interaction, $F(1, 40) = 494.0$, $p < 0.001$, $\eta_p^2 = 0.925$. This interaction was followed up with paired *t*-tests for which Cohen's *d* was used as a measure of effect size. Cohen's *d* was calculated by dividing the mean difference by the standard deviation of the difference scores, as provided by SPSS. Paired *t*-tests revealed that the manual-far condition had significantly longer RTs than manual-close, $t(40) = 29.5$, $p < 0.001$, $d = 4.606$, and equally, automatic-far had longer RTs than automatic-close, $t(40) = 13.27$, $p < 0.001$, $d = 2.073$. RTs to the far distance were longer in both selection modes, however a visual inspection of the results suggests that the RT difference between close and far was much more substantial in the manual selection mode, $M_{\text{difference}} = 127.2$ ms, 95% CI [118.55, 135.99], than the automatic selection mode, $M_{\text{difference}} = 27.4$ ms, 95% CI [23.22, 31.56].

For errors of commission, there was a main effect of selection, $F(1, 40) = 216.3$, $p < 0.001$, $\eta_p^2 = 0.844$, with fewer errors made in manual ($M = 0.03$, $SD = 0.06$) than automatic ($M = 0.40$, $SD = 0.18$). There was no main effect of distance (close $M = 0.22$, $SD = 0.14$; far $M = 0.22$, $SD = 0.10$), $F(1, 40) = 0.003$, $p = 0.959$, $\eta_p^2 = 0.000$, however there was a significant interaction between selection and distance, $F(1, 40) = 6.17$, $p = 0.017$, $\eta_p^2 = 0.134$. Manual-far had significantly fewer commission errors than manual-close, $t(40) = 3.05$, $p = 0.004$, $d = 0.476$, but there was no significant difference between automatic-far and automatic-close, $t(40) = 1.20$, $p = 0.238$, $d = 0.187$. Distance did not appear to be a factor in the automatic condition, yet in the manual condition fewer commission errors were made at the far distance.

Errors of omission were generally low, yet there was a main effect of distance, with significantly more omission errors made to stimuli at the far ($M = 0.011$, $SD = 0.01$) distance than to stimuli at the close ($M = 0.006$, $SD = 0.01$) distance, $F(1,40) = 8.07$, $p = 0.007$, $\eta_p^2 = 0.168$. There was no difference between omission errors for manual ($M = 0.011$, $SD = 0.01$) versus automatic ($M = 0.006$, $SD = 0.02$) selection modes, $F(1, 40) = 2.05$, $p = 0.160$, $\eta_p^2 = 0.049$, however there was a significant interaction between distance and selection, $F(1, 40) = 12.30$, $p = 0.001$, $\eta_p^2 = 0.235$. Paired *t*-tests showed that there was a difference within the manual condition, with significantly more omission errors made to far than to close, $t(40) = 3.66$, $p = 0.002$, $d = 0.572$, but no difference within the automatic condition, $t(40) = 0.72$, $p = 0.474$, $d = 0.113$. The greater amount of omission errors to far stimuli than close stimuli was therefore due to a difference within the manual condition. While this could have been simply due to participants not having enough time to move the cursor to the farther boxes, the fact that very few responses were recorded near to the 1000 ms time suggests that participants did in fact have sufficient time to make responses in all conditions.

It was noted that errors of commission were relatively rare in the manual selection condition (although a paired *t*-test showed that significantly fewer commission errors were made to far stimuli than to close stimuli within the manual condition). To provide further insight into how participants' ability to withhold changed over the conditions, an additional metric was used. Using the data from cursor movements during the manual condition, it was possible to tell whether or not the stimuli box was entered during each trial. The X and Y coordinates of the mouse cursor every 20 ms during the trial were examined. Through this it was apparent that while participants in the manual condition had successfully withheld responses to No-Go stimuli for the vast majority of the time, they had physically moved the cursor to the box which a No-Go stimulus had appeared in. On average, participants moved their cursor into the stimuli's box 70% of the time. It was thought that this could provide further insight into how participants' ability to withhold may have been affected by manual selection as well as distance. As only the manual condition was applicable here, a paired samples *t*-test was done to see how distance affected "box entries." There were significantly fewer box entries to far boxes ($M = 0.61$, $SD = 0.17$) than to close boxes ($M = 0.79$, $SD = 0.16$), $t(40) = 5.80$, $p < 0.001$, $d = 0.905$.

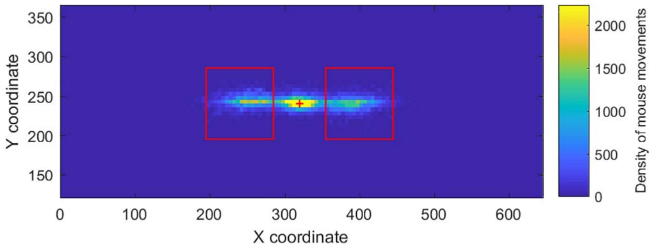

Fig. 3. Density plot depicting X and Y coordinates of all participants' mouse cursor movements during manual-close Go trials which were scored "correct".

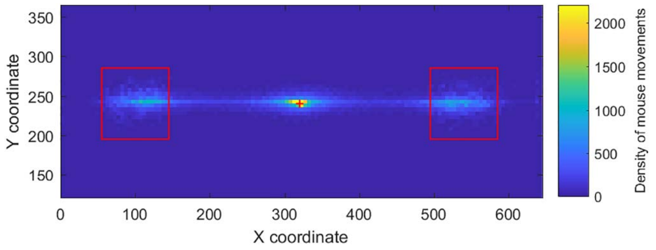

Fig. 4. Density plot depicting X and Y coordinates of all participants' mouse cursor movements during manual-far Go trials which were scored "correct".

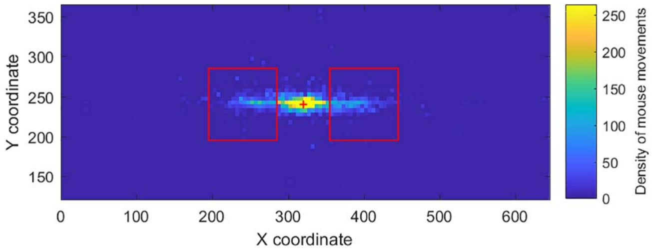

Fig. 5. Density plot depicting X and Y coordinates of all participants' mouse cursor movements during manual-close No-Go trials which were scored "correct".

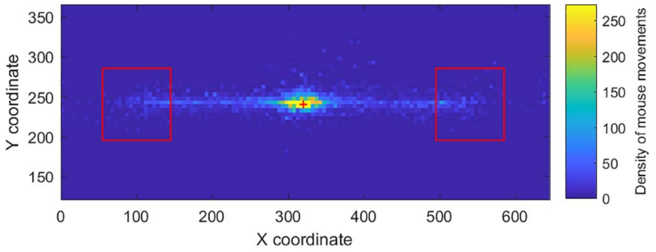

Fig. 6. Density plot depicting X and Y coordinates of all participants' mouse cursor movements during manual-far No-Go trials which were scored "correct".

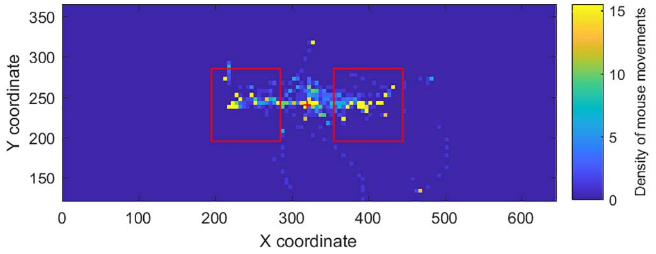

Fig. 7. Density plot depicting X and Y coordinates of all participants' mouse cursor movements during manual-close No-Go trials which were scored "incorrect".

Density plots were created to visually depict the density of participants' mouse movements in the manual condition. The figures below

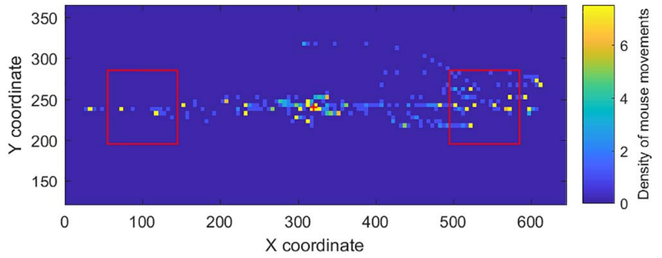

Fig. 8. Density plot depicting X and Y coordinates of all participants' mouse cursor movements during manual-far No-Go trials which were scored "incorrect".

(Figs. 3–8) take into account the position of the cursor (using the recorded X and Y coordinates) over several of the different trial types while also classifying the outcome of the trial (correct or incorrect; commission error). The two squares on each figure represent the boxes whereas the '+' represents the fixation cross at the beginning of the trial and the central point at which the cursor was positioned by default.

3.2. Subjective state

Each participant's mean subjective ratings of each item on both the Stress Scale (Table 2) and the modified NASA-TLX (Table 3), for both the manual and automatic selection conditions were calculated. Scores for close versus far distance could not be analysed here given this manipulation occurred at the within-task level rather than the between-task level. Paired samples *t*-tests were conducted to see how the selection manipulation affected each of the subjective ratings. To calculate Cohen's *d*, mean differences were divided by the standard deviation of the difference scores. To control for familywise error rate the Holm-Bonferroni procedure was used. Bayes factors were calculated in order to better evaluate the support for and against the null and alternative hypotheses. The JZS Bayes Factors were used as recommended by Rouder, Speckman, Sun, Morey, and Iverson (2009). These generate the odds for and against the null-hypothesis versus a reasonable alternative hypothesis. The Bayes factors reflect the odds of support for the hypothesis specified within the table. Both the non-adjusted and the adjusted *p*-values as well as the Bayes factors can be found in the tables.

Ratings of physical demand were higher for manual selection than automatic selection, $t(40) = 5.34$, $p < 0.001$, $d = 0.837$, and similarly, physical fatigue was higher for manual selection than automatic selection, $t(40) = 2.29$, $p = 0.027$, $d = 0.358$ (although this was not significant when using the adjusted *p*-values). However, neither mental demand, $t(40) = 1.92$, $p = 0.063$, $d = 0.299$, nor mental fatigue, $t(40) = 0.14$, $p = 0.891$, $d = 0.022$, were significantly different between the manual and automatic conditions. There was also no significant difference for levels of TUTs between the manual and automatic conditions, $t(40) = 1.28$, $p = 0.209$, $d = 0.199$. Also significantly higher for the manual condition than the automatic condition were ratings of concentration, $t(40) = 3.58$, $p = 0.001$, $d = 0.559$, confidence, $t(40) = 3.74$, $p = 0.001$, $d = 0.585$, TRTs, $t(40) = 2.24$, $p = 0.031$, $d = 0.350$ (however this was not significant when considering the adjusted *p*-values), and global workload, $t(40) = 2.84$, $p = 0.007$, $d = 0.444$. There were no other differences between the manual and automatic conditions, $p > 0.05$.

Whether TRTs or TUTs were higher for each of the two conditions was also investigated, as these two items afford an easy and useful comparison with each other. Paired samples *t*-tests revealed that for the manual condition, TRTs were significantly higher than TUTs, $t(40) = 4.34$, $p < 0.001$, $d = 0.678$. Similarly for the automatic condition, TRTs were significantly higher than TUTs, $t(40) = 2.47$, $p = 0.018$, $d = 0.385$.

3.3. Correlations

3.3.1. Correlations between RT and commission errors

Pearson product–moment correlation coefficients were used to analyse the relationships between RT and commission errors for each of the conditions ($N = 41$ in all cases; see Table 4). There was a significant negative correlation between RT and commission errors in both the automatic condition and the manual condition. Both conditions were then broken down to investigate Distance as well. There were significant correlations indicative of speed–accuracy trade-offs for every condition except the manual-far condition.

3.3.2. Correlations between SART performance and subjective state

Correlations between SART performance measures and each of TUTs, TRTs, and concentration were examined. For Manual selection, neither commission errors nor RT correlated significantly with TUTs, TRT, or concentration, $p > 0.05$. For Automatic selection, commission errors were positively correlated with TUTs, $r = 0.314$, $p = 0.046$, but not with TRTs or concentration, $p > 0.05$. RTs were negatively correlated with TUTs, $r = -0.323$, $p = 0.040$, but were not significantly correlated with TRTs or concentration, $p > 0.05$.

Partial correlations were then conducted for Automatic selection to control for the influence of RT. The partial correlation between commission errors and TUTs when controlling for RT was $r = 0.172$, $p = 0.289$, while the partial correlation between RT and TUTs when controlling for commission errors was $r = -0.189$, $p = 0.243$.

Table 2
Stress Scale ratings for the manual and automatic conditions.

	Manual	Automatic	*d*	Non-adjusted *p*-values	Adjusted *p*-values	Bayes factors
Physical fatigue*	4.12 (2.72)	3.24 (2.70)	0.358	0.027	0.243	1.73, alt
Mental fatigue	4.95 (2.85)	5.00 (2.84)	0.022	0.891	1.00	5.84, null
Tense	3.95 (2.93)	3.93 (2.50)	0.013	0.933	1.00	5.91, null
Unhappy	2.85 (2.52)	3.41 (2.73)	0.302	0.060	0.42	1.10, null
Motivation	6.17 (2.10)	5.76 (2.35)	0.205	0.197	0.985	2.68, null
Task Interest	4.02 (2.41)	3.46 (2.63)	0.246	0.123	0.738	1.90, null
Self-related thoughts	3.20 (2.10)	3.39 (2.13)	0.088	0.574	1.00	5.10, null
Concentration**	7.00 (1.83)	6.17 (2.11)	0.559	0.001	0.011	33.0, alt
Confidence**	6.71 (1.66)	5.76 (1.53)	0.585	0.001	0.011	50.0, alt
TRTs*	7.00 (2.07)	6.22 (2.04)	0.350	0.031	0.248	1.57, alt
TUTs	4.20 (2.65)	4.71 (2.27)	0.199	0.209	0.985	2.78, null

Values in parentheses represent standard deviations.
alt = in favour of alternative hypothesis, null = in favour of null hypothesis.
** $p < 0.01$.
* $p < 0.05$.

Table 3
NASA-TLX ratings for the manual and automatic conditions.

	Manual	Automatic	*d*	Non-adjusted *p*-values	Adjusted *p*-values	Bayes factors
Physical demand**	3.39 (2.01)	1.71 (1.68)	0.833	< 0.001	0.007	4929, alt
Mental demand	5.83 (2.26)	5.39 (2.31)	0.299	0.063	0.315	1.13, null
Temporal demand	5.66 (2.15)	5.51 (2.10)	0.077	0.625	1.00	5.29, null
Effort	5.80 (2.33)	5.59 (2.28)	0.102	0.517	1.00	4.85, null
Emotional demand	2.66 (1.87)	2.59 (2.11)	0.038	0.808	1.00	5.76, null
Performance monitoring demand	5.48 (2.20)	5.72 (2.16)	0.161	0.313	1.00	3.65, null
Global Workload**	4.79 (1.53)	4.40 (1.54)	0.444	0.007	0.042	5.45, alt

Values in parentheses represent standard deviations.
alt = in favour of alternative hypothesis, null = in favour of null hypothesis.
** $p < 0.01$.

Table 4
Correlations (*r*) between RT and errors of commission for each condition.

Manual		Automatic	
− 0.371*		− 0.552**	
Manual-Close	Manual-Far	Auto-Close	Auto-Far
− 0.42**	− 0.09	− 0.50**	− 0.48**

** $p < 0.01$.
* $p < 0.05$.

4. Discussion

The current experiment employed a modified version of the SART to investigate the effects that, 1) changing the physical method of acquiring targets and 2) manipulating target distance, had on SART performance. This was done with two manipulations: Firstly, to respond to stimuli participants were required to either make no movement except to press the mouse button, or to make a movement to the location of the stimulus before pressing the button. Secondly, stimuli were either located at a close distance to a central point or farther away.

Both the perceptual decoupling explanations and a simple response strategy explanation of SART responding predict that manual response movement should have led to slower RTs and fewer commission errors, which was indeed observed in the results. Where the two theories differ in terms of their predictions about the behavioural results though, are the effects of distance on performance and the likelihood of an interaction effect between the mode of selection and distance. The response strategy view would predict that manual selection would yield greater commission errors when distance is shorter, but in the automatic condition commission errors should be the same irrespective of the distance.

In line with a response strategy explanation, there were main effects of distance, with stimuli at the far distance yielding both slower RTs and fewer commission errors. There were also interaction effects between selection and distance. While there were longer RTs to far stimuli than to close stimuli for both automatic and manual selection, the difference was much more substantial within the manual condition. In terms of commission errors, fewer errors were made to far stimuli than to close stimuli when selection was manual, but there was no difference between the distances when selection was automatic. Effectively, target distance had much more influence on RTs and commission errors when selection was manual than when it was automatic.

Self-reported ratings revealed that, unsurprisingly, physical demand and physical fatigue were higher for manual selection. The two perspectives on SART performance differ in their predictions of mental fatigue and demand though. From a perceptual decoupling perspective, the condition where RTs were slower and commission errors were fewer (manual selection) should have provided more exogenous support of attention, thereby preventing perceptual decoupling and leading to those observations of slower RTs and fewer commission errors. This should be reflected by higher ratings of mental demand and mental fatigue. Conversely, a response strategy perspective posits that the difference in SART performance here could be explained by the physical differences alone. The results revealed no differences for mental demand or mental fatigue between the manual and automatic conditions, thus we failed to find evidence consistent with a perceptual decoupling explanation.

Another point where the two different perspectives differ concerns TUTs. In the manual condition, where from the perceptual decoupling perspective there should be less mind-wandering or TUTs than in the automatic condition, we found no evidence for much of a difference in self-reported TUTs. The difference in TUTs between the two conditions was according to a Bayesian analysis approximately 3 to 1 in favour of the null hypothesis. The tasks were, however, perceived differently. Indeed the manual task was perceived as more demanding than the automatic task with increased reports of physical demand and when global workload was calculated, increased global workload. The only workload measure that numerically was higher for the automatic task than the manual task was performance monitoring demand (though not statistically significantly different). There were also differences in self-reports of concentration, confidence, and TRTs. The two tasks do place different demands on the person and this is recognized by participants. The automatic task is much more likely to result in inhibition failures (commission errors) and these are probably noticed by participants. Indeed in previous research, normal (non-brain-damaged) participants report near 100% awareness of commission errors in the SART (McAvinue et al., 2005) and there is noted post commission error response slowing in the SART (Manly, Davison, Heutink, Galloway, and Robertson, 2000; Robertson et al., 1997). Participants reported elevated concentration and confidence in the manual SART in comparison to the automatic SART. This may be because they objectively perform better in terms of commission errors in the manual SART than the automatic SART. We suspect some researchers may have underestimated the role that actual task performance may have on self-reports given during or after the task (see Head and Helton, 2016). If performance is perceived to be relatively good, then participants may report improved confidence and concentration, even if they are not preoccupied by more TUTs to any substantial degree. However, there is also the possibility that self-reports of TUTs are also contaminated by performance awareness and appraisal.

The perceptual decoupling account of the SART, whose proponents suggest errors of commission in the SART are due to a lack of external awareness caused by preoccupation with TUTs, would also suggest strong correlations between TUTs and commission errors. As a speed–accuracy trade-off is a known factor in the SART, some researchers promoting this perspective have advocated controlling for the SATO by factoring out response speed (i.e., response time) statistically from the relationship between TUTs and errors of commission (Seli, Jonker, Solman, Cheyne, and Smilek, 2013). This statistical solution only controls for static between-subjects differences of the SATO. Some individuals tend to react hastily and thus, tend to be commission error prone; whereas others tend to react slowly and thus are less commission error prone. This, however, neglects the real insight of Peebles and Bothell's (2004) ACT-R model in which the SATO is a process that occurs within an individual as they experience the SART. The participant is trying to balance the competing demands of the SART: to respond as quickly and accurately as they can which are incompatible demands. As most of the stimuli in the SART are Go stimuli, responding more quickly is usually rewarded as the participant will often encounter runs of Go stimuli. Only when a relatively rare No-Go stimuli is encountered does the quick response strategy fail and since this is noticed by the participant there is an immediate shift in response strategy to encourage increased caution. This is well noted in the SART as post commission error responses are typically slow and RTs preceding commission errors are relatively fast (e.g., Manly et al., 2000). The SATO, in addition to varying between individuals, also varies dynamically within individuals. Thus, between-subjects analyses do not entirely eliminate the SATO. Despite the apparent confusion of a between-subjects and a within-subjects SATO processes in the literature, we nevertheless have reported the correlations (partial) between TUTs and commission errors controlling for RT.

Even in the case of automatic selection the correlation between TUTs and commission errors when RT is partialed out is $r = 0.172$ (statistically non-significant). In other words when the between subjects SATO is statistically controlled there is approximately 3% shared variance between TUTs and commission errors. While this may provide some marginal support for the mind-wandering and perceptual decoupling perspective of commission errors, we advocate continued skepticism regarding this interpretation. This partial correlation means 97% of the variance in errors of commission is not shared with TUTs. In addition, the slight shared variance could be due to two alternative possibilities instead of the interpretation that TUTs are a cause for errors of commission. First, individuals who tend to report TUTs or are TUT prone, may also have a tendency to have poor motor inhibition. Indeed, Kane and colleagues (McVay and Kane, 2009) have suggested and have provided some evidence that TUTs are a consequence of executive control failures not necessarily causes for control failures. Second, normal individuals report being nearly 100% aware of commission errors in the SART (McAvinue et al., 2005). This suggests awareness of commission errors may instead contaminate TUT self-reports. If a person realizes they are making errors in the SART it may be natural to assume the reason for those errors is that the person was not paying attention enough to the task (Head and Helton, 2016). Thus, errors of commission may be a cause for TUTs, not the other way round. Nevertheless, we think it may be questionable to make too much of these post-hoc self-reports and weak, possibly spurious, associations with commission errors.

The significant negative correlations between RTs and commission errors (speed–accuracy trade-off) for both of the automatic selection conditions are consistent with typical SART findings (Helton et al., 2005; Helton et al., 2009; Wilson, Russell, et al., 2015). Unexpectedly, one of the manual selection conditions (manual-close) also demonstrated a speed–accuracy trade-off. It could be that the close boxes were close enough that the response movement they required was still relatively easy to perform quickly. This could have encouraged the development of a motor program (see Keele, 1968) within the manual-close condition too, leading to difficulty withholding responses to No-Go stimuli. A visual examination of the density plots depicting mouse cursor movements supports this, showing that on No-Go trials (even those scored 'correct') participants frequently moved the mouse into the close boxes (Fig. 5) but more often refrained from moving the mouse into the far boxes (Fig. 6). Head and Helton (2013) also observed this and a similar explanation to what they gave is offered here, in that participants are likely to have become skilled enough at making responses to close boxes in the manual condition, that they were susceptible to speed-induced errors, just as they were in the automatic selection condition (though to a much lesser degree). The manual-far trials, where stimuli were in far boxes within the manual condition, as predicted, did not lead to a speed–accuracy trade-off. These trials also yielded the slowest RTs and, as expected, had the lowest rate of commission errors. Conversely, the condition with the strongest correlation was automatic-close which had the shortest RTs and the highest errors of commission rate. It appears that as RTs shorten, the association between RTs and commission errors becomes stronger.

The finding that the far distance reduced commission errors, but that importantly this was only during the manual condition and not the automatic condition, suggests that the RT delay gave participants more time to inhibit a prepotent motor response routine and thereby stop themselves from making commission errors more often. The longer distance may have only led to a 3% decrease in commission errors, but this was a drop from 5% (close) to 2% (far); in other words, this manipulation more than halved commission errors. This contrasts with a perceptual decoupling perspective, wherein the reduction in commission errors would be explained by the manual response re-engaging participants, or preventing them from becoming perceptually disengaged in the first place. It appears that this perspective cannot account for the difference in SART performance that the small change in distance yielded however. Further supporting the idea that the increased distance gave participants more time to inhibit prepotent motor responses is the finding that, within the manual condition, despite participants making relatively few commission errors overall, their mouse cursor movement patterns suggest that they frequently *almost* made errors of commission. That is, on approximately 70% (77% for Close boxes; 61% for Far boxes) of No-Go trials in the manual condition, participants actually physically moved the cursor into a box containing a No-Go stimulus, which can clearly be seen in the density plots. However, most of the time participants were able to prevent themselves from carrying out the final step to making a response—clicking the mouse. This indicates that the prepotent motor response routine developed not only in the automatic condition but the manual condition too, however in the manual condition it was *manageable*, e.g. it often did not lead to commission errors. This reduction in commission errors found in the manual condition is consistent with findings elsewhere (Head and Helton, 2013, 2014a, 2014b).

The subjective reports, when considered alongside the SART performance results, provide further support for a response strategy explanation of SART performance as opposed to a perceptual decoupling explanation. The reports suggest that the improved performance in the manual condition was a result of physical or motor factors, as opposed to mental or perceptual factors. The lack of any observed difference in TUTs between the two different methods of selection further implies that the much higher commission error rate for automatic selection was not due to participants disengaging their attention to the task per se. One limitation of the subjective measures employed however was that we were only able to examine the effect that selection had and were unable to parse out the effect that distance itself had, because selection varied from condition to condition (between tasks) whereas distance varied from trial to trial (within task).

While there may be some involvement of sustained attention in the SART, this is likely an internally directed as opposed to an externally directed form of attention, such as perceptual awareness (Helton et al., 2009; Helton, Weil, Middlemiss, and Sawers, 2010). SART performance appears to be associated with executive control of the prepotent motor response routine. This is different to the type of sustained attention that the majority of authors using the SART intend to measure.

The finding within the manual selection condition, that more omission errors were made to Go stimuli in the far-distance boxes than to close-distance boxes, could have been due to participants not having enough time to move their mouse cursor and make their response on some trials. However, the way in which response times were distributed suggested that participants had sufficient time to make responses in this condition. Perhaps this finding is due to participants taking tactical rest breaks in response to task demands. Indeed, this condition was likely the most demanding and ratings of global workload and physical demand were higher for manual selection. Increased omission errors due to participants taking tactical rest stops has been proposed in previous research with the SART (Finkbeiner et al., 2015; Helton et al., 2011). Nevertheless, overall omission errors were very low (between 0 and 2%) and so this result should be treated with caution.

The current experiment may also have important implications for some applied contexts, such as modern warfare. The possible relation of the SART and response inhibition errors to the use of firearms has already been demonstrated; in this case with a military simulation using human actors representing dismounted soldiers (see Wilson, Head, et al., 2015). Furthermore, Helton and Kemp (2011) suggest that the fast, easy and short-distance hand movements that some unmanned vehicle weaponry systems offer could make operators more vulnerable to committing friendly fire errors. New technology is driving the development of increasingly automated weapons systems. Some of these systems, such as the Korean-made “Super aEgis II” sentry gun, are able to identify and lock on to targets without any involvement from a human operator (Egeland, 2014). This removes the need for a human operator to both detect the target and then aim at the target by physically moving the weapon towards it. Instead the operator may only be required to pull a trigger, or push a button, to deploy the weapon. An operator could essentially be faced with a stream of potential targets appearing on a screen, for which they will be encouraged to make rapid shoot/no-shoot decisions about, despite perhaps having limited or incomplete knowledge about the targets given the short timeframe. The nature of a task such as this has clear similarities with the SARTs used in the current experiment. The current findings suggest that as weapons systems become more automated, the chances of accidental shootings (e.g. friendly fire) will increase. Indeed, in the current experiment, changing only the *selection* of stimuli from manual to automatic elevated commission errors (accidental responding) from 3% to 40%. While the nature of the SART (a high Go, low No-Go task with a high rate of stimuli presentation) contributes to the high commission error rate seen in the current experiment and other SART research too, it still seems likely that the risk of accidental shooting could become worryingly high in real-life situations, particularly as operators may encounter high rates of potential targets within short periods of time (e.g., like the SART).

In terms of future research, if a paradigm similar to the one employed here is used it may be useful to look at the effect that distance itself has on subjective thought measures, something which we were unable to do here. One possibility would be to examine responses to far targets versus close targets over separate tasks, to enable post-task measurement of subjective thoughts for each distance.

In the current experiment, implementing a manual response selection condition led to slower RTs, fewer commission errors, and weaker speed–accuracy trade-offs. Furthermore, manipulating this manual response by increasing the distance participants had to move with their mouse cursor notably exaggerated these effects. However, this was not seen in the automatic selection condition when distance was manipulated. Subjective self-reports suggested that the performance difference between manual and automatic selection was not due to any differences in mental demand or fatigue, but may instead be due to physical factors. Collectively, these findings support a response strategy perspective of SART performance, as opposed to a perceptual decoupling perspective. The findings also suggest that in real-world tasks or situations where failures of response inhibition (e.g. commission errors) may occur, if an operator's or user's responding can be slowed down, they will be better able to prevent these failures from occurring. Introducing an artificial delay appears to provide a degree of protection against commission errors.

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