The Effects of Response Probability on Commission Errors in High Go Low No-Go Dual Response Versions of the Sustained Attention to Response Task (SART)

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Abstract

In the current investigation, we modified the high Go low No-Go Sustained Attention to Response Task (SART) by replacing the single response on Go trials with a dual response (dual response SART or DR SART). In three experiments a total of 80 participants completed the SART and versions of the DR SART in which response probabilities varied from 50-50, through 70-30 to 90-10. The probability of No-Go withhold stimuli was .11 in all experiments. Using a dynamic utility based model proposed by Peebles and Bothell (2004) we predicted that the 50-50 DR-SART would dramatically reduce commission errors. Additionally, the model predicted that the probability of commission errors to be an increasing function of response frequency. Both predictions were confirmed. Although the increasing rate of commission errors with response probability can also be accommodated by the rationale originally proposed for the SART by its creators (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) the fact that the current DR SART results and SART findings in general can be accommodated by a utility model without need for any attention processes is a challenge to views that ascribe commission errors to lapses of sustained attention.

Introduction

Every day, we find ourselves in situations that require us to remain attentive over short periods of time. It could be keeping an eye on traffic signals, or making sure you catch your flight details on the screens at the airport. Being unable to do so could have costly consequences, in the former case it could mean your life and the lives of others; in the latter case you could miss your connecting flight and be stuck in transit limbo for days. Either way, it is important that we are able to sustain attention until the task is complete. But what exactly is sustained attention?

The Encyclopaedia Britannica (McCallum, 2014) broadly describes sustained attention as a state in which attention must be maintained over time, often found in 'watchkeeping' activities where an observer must continuously monitor a situation in which significant, but usually infrequent and unpredictable, events may occur. The creators of the Sustained Attention to Response Task (SART) presented a more precise definition of sustained attention: it is 'the ability to self-sustain, mindful, conscious processing of stimuli whose repetitive, non-arousing qualities would otherwise lead to habituation and distraction to other stimuli ' (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997, p.748). Subsequently, and more pertinent to the current study, Langer and Eickhoff (2013) define sustained attention as the process of sustaining efficient conscious stimulus processing over periods longer than about 10 seconds up to many minutes.

Laboratory research and observations in the field have shown that sustaining attention to simple, monotonous tasks is perceived as highly demanding and effortful, causing subjective strain or perhaps even fatigue over time (Langner & Eickhoff, 2013). Subsequently, several researchers have proposed that such subjective experiences as well as concurrent objective difficulties in maintaining performance levels are a direct result of depletion of attentional resources that is caused by continuous allocation of attention (Grier et al., 2003; Helton 2009; Helton et al. 2005, Helton, Kern, & Walker, 2009; Helton & Warm, 2008). In contrast, others have argued that cognitively more challenging or interesting tasks like video/computer gaming (as opposed to radar monitoring), may place similar or higher demands on attention but still fail to evoke any subjective experiences of strain and fatigue or even objective performance deterioration over time; instead such tasks can actually induce a positive 'flow' experience (Langner & Eickhoff, 2013). Subsequently, Langner & Eickhoff (2013) argue that negative subjective experiences in prolonged simple, repetitive tasks can be interpreted as reflecting the experience of boredom (Scerbo, 1998), which previous studies have indicated as having an association with increased absentmindedness/mindlessness and mind-wandering (Cheyne, Solman, Carriere, & Smilek, 2009; Manly, Robertson, Galloway, & Hawkins, 1999; O'Connell et al. 2006; Robertson et al. 1997; Smallwood et al., 2004).

The basic experimental paradigm for assessing vigilant or sustained attention involves participants monitoring their environment for a (more or less frequently occurring) pre-specified target. Most research tends to use either of the following paradigm subtypes:

(a) sustained covert (i.e., silent) target counting.

(b) continuous stimulus detection (i.e., non-cued simple reaction time tasks) which does not require stimulus identification since all presented stimuli are targets. There is only one invariable response, and the only uncertain aspect is the exact moment of stimulus occurrence.

(c) continuous stimulus discrimination (i.e., non-cued Go/No-Go tasks), where targets and non-targets are presented in an intermixed fashion (typically unpredictably), with targets requiring a response and non-targets requiring no overt response. Traditionally, Go/No-Go tasks used in research contain many more non-target (No-Go) than target (Go) events, such as Mackworth's Clock Task (Mackworth, 1948) or the classic Continuous Performance Task (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). Recently, 'reverse' vigilance paradigms with more Go than No-Go events, such as Conners's CPT (Conners, 1994) or the SART (Robertson et al., 1997), have garnered much interest. The SART in particular has been the go-to 'reverse' vigilance paradigm for many researchers studying sustained attention.

The SART

The original SART procedure (Robertson et al., 1997) involved the visual presentation of 225 single digits (25 for each of the 9 digits) over 4.3 minutes. A single trial was comprised of (see Figure 1):

I – A digit presented for 250 msec.

II – Followed by a 900-msec mask (ring with a diagonal cross in the middle)

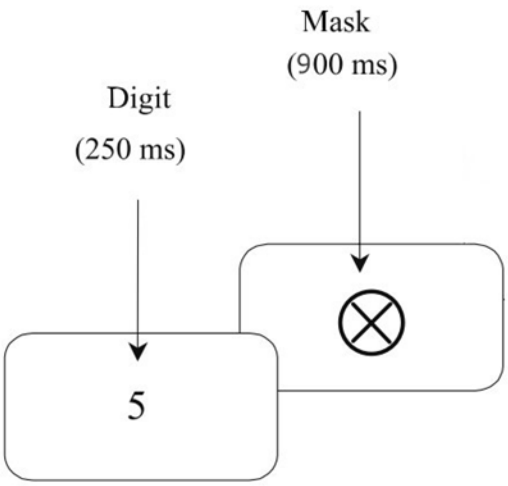

Fig. 1 A single trial sequence during the SART

Subjects responded to each digit with key presses (go stimuli), except on the 25 (11.1%) occasions that the digit 3 (no-go stimulus) was presented. Robertson and colleagues distributed the digit 3 throughout the 225 trials in a pre-fixed quasi-random manner. Furthermore the digits were randomly allocated to 5 various font sizes to ensure that the numerical value would be processed and not peripheral features of the no-response target.

'Oops!' Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects.

As mentioned earlier, Robertson et al. (1997) define sustained attention as 'the ability to self-sustain, mindful, conscious processing of stimuli whose repetitive, non-arousing qualities would otherwise lead to habituation and distraction to other stimuli '. Using examples like keeping vegetable peelings while throwing away the vegetables themselves or pouring cream into black coffee, they illustrate action slips which they believe may have a possible link with sustained attention abilities. They argue that this link and thereby the conception of the Sustained Attention to Response Task (SART) is important for two reasons: First, attentional performance measures that correlate with slips of action (in the normal population) have not been very successful and Robertson and colleagues believe that this is due to inadequate measures of sustained attention. Second, they argue that there is insufficient characterization of attention deficits in patients with Traumatic Brain Injury (TBI).

Robertson and colleagues argue that action slips among the normal population and attentional failures in TBI patients share some (less extreme) characteristics, and that these slips are influenced by transient attention lapses to tasks symptomatic of deficient sustained attention. They believe that the difficulty in establishing dependable performance correlates of sustained attention failures in TBI patients may be due to the nature of the sustained attention paradigms employed. Robertson and colleagues suggest the near ceiling performance levels commonly found may not require conscious deliberate processes or sustained attention at all, but instead targets may be detected automatically in the sense of Schneider & Shiffrin (1977).

Robertson and colleagues believed that reversing the relative probability of Go and No-Go stimuli would create a situation where responses to the common go stimuli become automatized. They argued that without sustained attention to their responses participants would mindlessly execute the automatized pre-potent response on No-Go trials. Thus, the frequency of responses to No-Go or withhold stimuli (i.e. commission errors) provides the sought sensitive measure of a person's ability to sustain attention. This was their justification for using a continuous performance paradigm with frequent key presses to go stimuli and a requirement to withhold key presses to occasional No-Go stimuli. They argued that this kind of task requires high levels of continuous attention and would be sensitive to a 'transitory reduction in attention' (attention lapses) with minimal involvement of other cognitive processes such as, memory, planning, and general intellectual effort. To test their hypotheses Robertson and colleagues conducted a rigorous set of experiments analysing the relationship between SART measures and everyday attentional lapses and other cognitive failures among normal controls; and the relationship between everyday attention failures and SART performance and brain damage severity among people with traumatic brain injury.

Robertson and colleagues found that performance of normal control subjects on the SART, which equates to a lack of commission errors to the No-Go stimuli, significantly correlated with self-reports of attentional and 'cognitive failures' in everyday life along with informant reports of similar failures. They concluded that difficulty in maintaining attention was a more satisfactory explanation for failures on the task than difficulty in inhibiting responses, which could be a problem since subjects would need to pay attention to reign in the tendency to automatically make a response to every stimulus. The SART measures demonstrated strong relationships with other validated measures of sustained attention but weaker relationships with measures of other attentional capacities including those with response inhibition components. Additionally, Robertson and colleagues were able to predict errors of commission (key presses to withhold stimuli) based on performance on correct Go trials preceding the presentation of a target, i.e. subjects' response times (RT) speed up prior to commission error responses. This is consistent with their argument that an error is not just an isolated failure in withholding a response but the result of a failure to maintain an optimum approach for the duration of the task.

***Look! It moves!* – Evolution of the SART**

The following decade saw the proliferation of the SART as a test of sustained attention. In the early 2000s a sequential SART was used where the number stimuli (1-9) where presented in a fixed rather than random order (Dockree et al., 2006; Manly et al., 2003), followed by SARTs with cues and response locking (Dockree et al., 2004; Dockree et al., 2006; Manly et al., 2004). A dual task version dubbed the DART (Dual attention to Response Task) was used by Dockree et al., (2006) where in addition to button presses to Go stimuli and no responses to No-Go targets, subjects were required to press a different button to grey coloured digits. O'Connell, Bellgrove, Dockree, & Robertson, (2006) used a SART that involved regular beeps to remind participants to concentrate on what they were doing. SARTs using global-local stimuli (Helton, Kern, & Walker, 2009; Helton, 2009; Helton, Weil, Middlemiss, & Sawers, 2010) and SARTs using feature present/absent stimuli were used in multiple studies (Helton & Russell, 2011; Stevenson, Russell, & Helton, 2011). Some studies have incorporated reliable or unreliable warnings in the SART (Helton, Head, & Russell, 2011) and others have used picture stimuli instead of digits (Head & Helton, 2012). There has also been an auditory and coloured versions of the SART used to great success (Seli, Cheyne, Barton, & Smilek, 2012; Smallwood, 2013).

In these variants of the SART, researchers customized the task based on the needs and requirements of their particular study. The SART has been used to study the effects of age, gender, and education on sustained attention (Carriere, Cheyne, Solman, & Smilek, 2010; Chan, 2001), and to investigate traumatic brain injury (Chan, 2005; Dockree et al., 2004; Manly et al., 2003; O'Keeffe, Dockree, & Robertson, 2004; O'Keeffe, Dockree, Moloney, Carton, & Robertson, 2007; Robertson et al., 1997; Whyte, Grieb-Neff, Gantz, & Polansky, 2006). It is a popular tool to assess attention difficulties in ADHD (Bellgrove, Hawi, Gill, & Robertson, 2006; Bellgrove, Hawi, Kirley, Gill, & Robertson, 2005; Johnson, Kelly, et al., 2007; Johnson, Robertson, et al., 2007; Manly et al., 2001; Mullins, Bellgrove, Gill,& Robertson, 2005; O'Connell et al., 2006) and to study attention related errors (Cheyne, Solman, Carriere, & Smilek, 2009). Versions of the SART have been used to study schizophrenia (Chan et al., 2009; Seok et al., 2012), sleep disorders (Van Schie et al., 2012) and depression (Farrin et al., 2003; Smallwood, O'Connor, Sudberry, & Obosawin, 2007). The SART has also been used in a study assessing work stress and burnout (Linden, Keijsers, Eling, & Schaijk, 2005), and to look at stress-induced cognitive effects of natural disasters (Helton, Head, & Kemp, 2011). A study even analysed the benefits of chewing gum on sustained attention based on the SART (Johnson, Muneem, & Miles, 2013). The SART is so popular today that when the words 'sustained attention tasks' are entered into Google, the first four or five results all link to the SART.

Despite its widespread use there has always been debate regarding the precise nature of the deficit measured by SART performance. Robertson et al., (1997) themselves acknowledge that the SART is sensitive to the ability to inhibit a response because if subjects aren't attending they will not notice what it is that they have to inhibit too, but Robertson and colleagues believed that their sustained attention argument is more credible. It has been variously argued that rather than being a measure of sustained attention, SART commission errors measure impulsive responding (Helton, 2009; Helton et al., 2009), response strategy (Helton et al., 2011; Helton, Weil, Middlemiss, & Sawers, 2010), executive motor control, (Head & Helton, 2013; Head & Helton, 2014) and the impact of speed-accuracy trade-offs (Peebles & Bothell, 2004; Seli, Jonker, Solman, Cheyne, & Smilek, 2013).

***The ghost in the shell* – What does the SART truly measure?**

The debate over SART measurement properties is crucial given its widespread use by researchers. Several experiments have been conducted that challenge the claim that the SART is a measure of sustained attention rather than motor control (response inhibition, response strategy or motor impulsivity). For the sake of exposition the measurement properties of the SART are explained individually, but it should be noted that they are all interlinked.

Response Inhibition:

In a follow up study (Manly, Robertson, Galloway, & Hawkins, 1999) reiterated their argument that performance on the SART requires sustained attention rather than a putative response inhibition capacity. They argued that performance is determined by the duration over which a person must maintain attention over their actions and that this demand supports the SART's relationship to common attention lapses. Conversely results from more recent studies suggest that failure to inhibit a pre-potent response rather than failure to perceive a critical stimulus is most likely the cause of SART commission errors (Helton et al. 2005). Stevenson et al., (2011) argue that these errors are what Robertson et al. (1997) interpret as lapses of attention whereas in traditional low-Go vigilance tasks decrease in detections over time (vigilance decrement) is the measure of interest. Despite participants in the SART being perceptually aware of the No-Go stimuli, they will often be unable to withhold a motor response (Carter, Russell, & Helton, 2013). Stevenson et al., (2011) believe that this leads to awareness of the task stimuli being (somewhat) masked by the demand exerted on motor inhibition. Consequently commission errors may occur because participants fail to perceptually identify the critical stimulus, or because perceptual identification does not itself necessarily prevent production of the pre-potent response.

Carter, Russell, & Helton (2013) explored the roles of attention and response inhibition by contrasting performance in SART and TFT tasks using highly predictable fixed ordered stimuli (1-9 sequentially) or unpredictable randomized digit sequences. They found more errors of commission in the unpredictable $\text{SART}_{\text{random}}$ condition, contradicting a previous study by O'Connell et al. (2009) who claimed that response inhibition demands were lower in the $\text{SART}_{\text{fixed}}$ than in the $\text{SART}_{\text{random}}$. Additionally Carter et al. found errors of commission were minimal in the TFTs (both random and fixed), which suggest that there is little need to inhibit responses in the low Go TFT task unlike the SART where the need to inhibit responses to rare No-Go stimuli is high. In fact, commission errors will occur on the TFT when there is a perceptual error, but they don't happen very often with clear high contrast digits. Carter, Russell, & Helton (2013) argue that the SART should not be used to measure the ability of subjects to sustain attention to external stimuli. They point out that since response inhibition is normally measured by the number of inhibition failures, i.e. inability to stop a response, errors of commission in the SART reflect failures of response inhibition not lapses in sustained attention. Analogous to arguments made by Stevenson et al., (2011), Carter, Russell, & Helton (2013) state that errors of commission in the SART are commonly made when the participant is completely aware of the No-Go stimuli but is unable to inhibit a pre-potent motor response. Consequently the numerous studies using the SART to measure sustained attention have likely measured something quite different, most likely strategies that relate to inhibition of a pre-potent motor response.

Motor Impulsivity:

Helton (2005) and Helton et al.,(2009) argue that the SART may be contaminated by impulsivity, and the constant responding to neutral signals leads to the development of a 'ballistic feed-forward motor program' which causes difficulty for the supervisory attention system in its capacity to control or inhibit. Thus a participant in the SART could be fully aware of the stimuli (perceptual awareness) but be unable to inhibit or disrupt this ballistic motor program. In fact, Head and Helton (2013) report that participants in their laboratory often recollect being fully aware during errors of commission on the SART while at the same time are unable to physically stop their hand from responding. Helton (2009) suggests that the SART's response format encourages conservativeness, i.e. the participants often try to harness or control their responses; and that this does not translate into being a failure of signal detection.

Additional evidence for a motor decoupling perspective on the SART includes the fact that task instructions seem to modify performance. Task instructions for the SART traditionally require participants to respond as quickly and accurately as possible, but when participants are asked to slow down (Seli, Cheyne, & Smilek, 2012) errors of commission dramatically decrease. Furthermore, when participants are instructed (via an audible metronome) to delay their responses (Seli, Jonker, Solman, Cheyne, & Smilek, 2012), errors of commission decrease. In fact, as Helton (2009) ironically points out, even research by Robertson and his colleagues (Manly, Robertson, Galloway, & Hawkins, 1999) supports an impulsivity perspective on the SART: increase in the probability of Go stimuli and an increase in overall event rate leads to increased errors of commission. In other words, people are impulsive because the benefit of fast responses (impulsivity) outweighs its costs.

Response Strategy:

Several studies have presented evidence indicating that the incidence of commission errors in the SART reflects response strategy rather than lapses in sustained attention (Head & Helton, 2014; Head, Russell, Dorahy, Neumann, & Helton, 2012; Helton et al., 2009; Peebles & Bothell, 2004). Helton (2009) conducted a study where participants performed global–local letter stimuli detection tasks using either the SART or the TFT. His findings indicated that performance on the SART changed rapidly over time, and demonstrated an inverse relationship between errors of commission and correct response reaction times (identical to Roberson and colleagues' initial findings). These results were regarded as evidence of strategic slowing. Helton (2009) also argued that participants in the global–local version of the SART strategically increased their response times in order to inhibit the impulsivity which caused the commission errors. There was no comparable strategic change in a perceptually identical TFT. Helton, Weil, Middlemiss, & Sawers (2010) interpret the Helton (2009) results as clear evidence for the role of response strategy in the determination of commission errors in the SART.

Furthermore, Helton et al. (2005) and (Helton 2009) argue that the SART is primarily a measure of speed-accuracy trade-off and response strategy. They suggest that errors of omission may be 'tactical forced rest-stops enabling enhanced inhibitory control', i.e. participants are taking a breather. Helton, Head, & Russell (2011) introduced warning cues of varying reliability into the SART to investigate its measurement characteristics and argue that if the SART is indeed a measure of sustained attention then reliable-warning cues should reduce errors of omission. But if Helton et al. (2005) and Helton's (2009) argument is correct errors of omission should occur more frequently with reliable-warning cues because errors of omission may be tactically used to improve commission error performance. Errors of omission were in fact higher in the reliable-warning cue SART than either a no- warning cue or an unreliable-warning cue SART adding further credibility to Helton and colleagues argument that the omission errors are tactical rest stops. This also provided additional support for the perspective that the SART is a better measure of impulse control and response strategy than sustained attention.

Mind Wandering:

Cheyne et al., (2009) presented a three-state attentional model of task engagement/disengagement that was applied to the SART. Based on the model, attentional disengagement during the SART can be described in three distinct states of mind-wandering:

State 1: Occurrent task inattention: which involves a brief or partial waning of detailed processing of moment-to-moment stimulus leading to a disengagement of attention from the features of the task. Commonly known as 'tuning out'. This state is reflected in the variably of RTs in the SART, and is especially observed via shorter mean RTs in the trials immediately prior to No-Go trials leading to SART errors (Manly et al., 1999; Robertson et al., 1997).

State 2: Generic task inattention: in which attention to the general task-relevant aspects of the environment is reduced but the individual continues to demonstrate well-practiced automatic responding. Commonly known as ‘going through the motions’ or ‘zoning out’. Reflected in the SART via anticipations, i.e. responses on Go trials that are way too fast to be responses to the Go stimuli, but could instead be a result of subjects anticipating the presentation of Go stimuli.

State 3: Response disengagement: which is evidenced by gross behavioural indicators of mind-wandering. Subjects may only be responsive to the most intrusive aspects of the task environment. Seen in the SART via omissions, i.e. the failure to respond to Go stimuli. Errors of omission have been noted to occur in the SART with both fixed and random intervals and researchers have interpreted them as a break from task engagement reflecting deteriorating attention (Johnson, Robertson, et al., 2007 as cited in Cheyne et al., (2009); Manly et al., 1999).

Various other studies have also shown that performance on the SART is a reliable index of mind wandering across a wide range of experimental methods (Cheyne et al., 2009; Christoff et al., 2009; Jackson & Balota, 2012; McVay & Kane, 2009; Smallwood et al., 2008). Yanko and Spalek (2013) argue that repeated engagement in a task will often result in gradual transition from being consciously aware and in control of one’s actions, to a state where automatic processes take over our actions placing a lower demand on attentional resources. Jackson & Balota, (2012) argue that the SART’s tendency to induce this shift from controlled to automatic processing is what makes it susceptible to mind-wandering.

Speed-accuracy:

Seli, Jonker, Solman, Cheyne, & Smilek, (2013) argue that since many studies that use the SART to observe sustained attention do not include RT data with mean error data, it is not possible to evaluate if improvements are caused by improved sustained attention or by strategic shifts along the speed–accuracy trade-off curve. But when mean RTs have been reported, the reductions in errors were also accompanied by slower RTs (Manly et al., 2004), indicating speed–accuracy trade-off effects. When Seli et al., (2013) investiged the effect of speed-accuracy trade-offs in the SART, they found that commission errors were a systematic function of various manipulations in response delay. Participants that were responding with a 400ms delay (after stimulus onset) produced the most errors; those responding with a 600ms delay made fewer errors and those responding with a 800ms delay produced even fewer errors. Even omission errors were lower with a 600ms and 800ms delay when compared to the standard SART and 400ms delay SART. Their results are a clear indication that manipulation of response delay affects error rate, providing further evidence that the SART is indeed susceptible to speed–accuracy trade-off effects.

Helton et al., (2009) designed an experiment to test if performance on the SART was influenced by prior exposure to emotional stimuli. The study also examined the influence that speed-accuracy trade-offs has on SART performance as demonstrated by Peebles and Bothell (2004), specifically the negative correlation between RT and errors of commission. They found that participants in their study prevented entering inappropriate responses by reducing the overall rate of response as illustrated by the high negative correlation between RT of appropriate responses and errors of commission ($r = -.61$). Therefore participants who were slow made fewer commission errors than participants who were faster. Helton et al., (2009) believe that subjects sacrifice speed for better accuracy and their results also support the argument that the SART is a better measure of response strategy and impulsive responding than attention.

Finally, a study by Seli, Cheyne, & Smilek (2012) investigated the effects of altering speed-accuracy tradeoffs via instructions, e.g. subjects were asked to focus on accuracy instead of both speed and accuracy (standard SART instructions state that speed and accuracy are equally important in successfully completing the task). They found that when instructions emphasized accuracy over speed there were fewer errors and a shift in the distribution of Go trial RTs (increased RTs and reduced errors). Seli, Cheyne, & Smilek (2012) argue that when subjects are given instructions for sustained attention tasks that emphasize both speed and accuracy it creates errors resulting from attempts by participants to conform to the 'misleading requirement for speed', which they believe becomes commingled with errors caused by attention lapses. Seli, Cheyne, & Smilek (2012) as an extension of remarks by Edwards (1961) argue that instructions such as those accompanying the SART are contradictory as speed and accuracy require modes of responding that are incompatible.

In addition to the debate over what the SART actually measures, the external validity of the SART has been questioned by Wallace, Kass, and Stanny (2002) and Whyte et al. (2006) who failed to show a significant correlation between performance on the SART and the Cognitive Failures Questionnaire (CFQ) which Robertson et al., (1997) used to demonstrate real world implications of the SART. Research by Whyte et al., (2006) in particular failed to replicate any of the key findings from the original research by Robertson and colleagues: that patients with TBI made more errors of commission on the SART than an uninjured control group, and that the number of errors correlated with everyday attention lapses as measured by the CFQ.

Sustained attention, by definition (e.g. Langer and Eichoff, 2013 as already noted) is about maintaining perceptual awareness to external stimuli, and not the setting of a speed–accuracy response policy or the inhibition of feed-forward motor programs. But many researchers, including Robertson and colleagues, still continue to use the SART as a measure of sustained attention (Dockree et al., 2004; Manly et al., 2004; Shaw et al., 2013) and make extensive efforts to salvage the SART as such a measure (Manly et al., 2003; Cheyne, Carriere, & Smilek, 2006; Connell et al., 2008; Seli, Cheyne, Barton, & Smilek, 2012). Manly et al. (1999), Farrin et al. (2003), and Van der Linden et al. (2005) have all found strong support for the Robertson's original claim. Van der Linden et al's., (2005) research on teacher burnout found that self-reports of cognitive complaints during the SART task to be significantly related to both SART errors and burnout status, and Farrin et al., (2003) demonstrated clear SART differences between depressed and non-depressed soldiers. Additionally, a study by Chan (2005) testing the sensitivity of the SART and the Monotone Counting Test found that subjects with mild TBI performed significantly worse in both tests than normal controls. In fact, performance on the SART was more sensitive to mild TBI than the Monotone Counting Test in the sample leading to Chan's (2005) conclusion that the SART is a valid measure of sustained attention.

Additionally, it is important to note that detecting a sudden onset (which could be the trigger for a pre-potent response) is not the same as identifying the digit or response class and even then it may be necessary to invoke a separate inhibition process. Multiple processes cascade at different rates in the brain. So it is possible for sudden onset to initiate a prepared pre-potent response before the stimulus is identified (a fraction later) and it is possible that stimulus identification is the signal to a stop-reaction like instruction, which will not prevent the response if it comes too late (Aron, 2011). So while it is important to understand the relevance of impulsivity, stimulus and response uncoupling, and inhibition of pre-potent responses, none of them may necessarily challenge Robertson and colleagues' claim that in order to control the pre-potent response one has to be paying attention to the action. Global strategies, such as setting a speed-accuracy criterion are insufficient because RTs change in response to errors (Robertson et al., 1997). This is where a dynamic model such as that presented by Peebles & Bothell (2004) has advantage – their model has mechanisms that support dynamic strategy changes, which while accounting for response inhibition, motor impulsivity, stimulus and perceptual decoupling, exposes the limitations of global explanations.

***To check, or not to check* –Modelling Performance in the Sustained Attention to Response Task.**

Peebles & Bothell (2004) proposed a computational model for human performance in the SART based on the ACT-R cognitive architecture (Anderson & Lebiere, 1998) which presented two competing strategies to explain the factors that may be responsible for the speed-accuracy trade-off often seen in the SART. The ACT-R 5.0 (Anderson et al., 2004)is a version of the ACT-R cognitive architecture that adds perceptual and motor modules giving the ACT-R, visual attention and processing mechanisms, basic speech and audition capabilities, including elements of motor control to simulate interaction with a computer keyboard and mouse. Peebles & Bothell, (2004) built an ACT-R model which mimics the manner of interaction between the SART and human participants, via a mouse and text on a computer screen (see Figure 2).

The model contains two competing strategies:

I-Encode and click: The faster option, but less accurate because the model straight away clicks the mouse after detecting any stimulus on the screen.

II-Encode and check: The slower option, but more accurate because the model first checks the stimulus to ensure that it should click the mouse and only does so when appropriate.

By presenting this strategy choice as an alternative explanation regarding performance, the model calls in question the role of sustained attention in the SART and provides an explanation for how the speed-accuracy trade-off occurs in the SART. According to Peebles & Bothell, the utilities of the two strategies ('encode and click' vs. 'encode and check') begin equal but change dynamically from trial to trial as a function of their histories of success and failure. Consequently the likelihood of application of each strategy varies from trial to trial capturing the dependence of Go response times on the recency of a commission error. When the probability of error is low the 'encode and click' strategy builds its utility over trials making this the more likely strategy, except after an error has occurred. When the probability of error is high, then the 'encode and check' strategy wins out but its high time cost lessens its utility quite quickly. So probability of error has the effect of modifying the utility of each strategy over trials. In this way their model relates the likelihood of commission errors to stimulus probability. Also, in addition to accounting for the response strategy and speed-accuracy aspects of the SART, the shift between strategies based on utility also explains why subjects are unable to inhibit a response or why they are prone to impulsivity ('encode and check' being the predominant strategy in both cases).

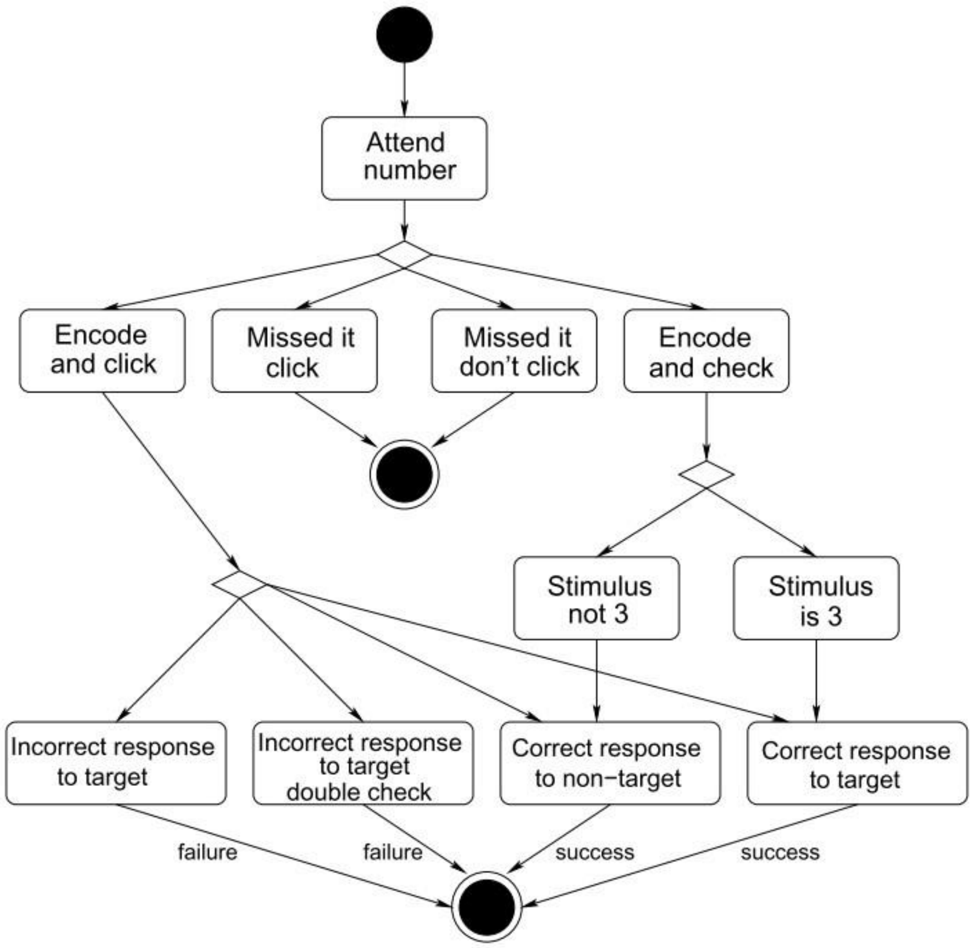

Fig. 2 Flow of processing in the ACT-R SART model. (Peebles & Bothell, 2004)

Furthermore, according to Robertson et al. to get a commission error two conditions are necessary: there is a) a pre-potent response and b) there is a lapse in attention. In the SART after the first minute or so, the pre-potent response will have been established, but the pre-potent response alone may not be sufficient to produce an error –an attention lapse is required as well. An important question then is whether the pre-potent response has to be controlled by attention on each trial or whether participants adopt some overarching strategy (e.g. 'encode and check' on every trial). The fact that commission errors occur at all suggests either that subjects don’t adopt an overarching strategy, or as Peebles and Bothell suggest, the strategy is subject to moment to moment variation. The strategies people adopt are known; their Go responses are faster before commission errors and slower afterwards (Robertson et al., 1997). This is not consistent with a static speed-accuracy trade-off or other constant strategy. Any strategy must be contingent upon recent events as Peebles and Bothell propose.

Subjects in the SART are given instructions which are impossible to carry out. They are told to respond as quickly to Go stimuli as possible without making errors on No-Go trials. According to the model, utility is a key concept here. Finding the balance between benefits (of fast correct responses) and costs (of commission and omission errors) is key. In the SART where No-Go stimuli are rare (11%) the benefits of speed far outweigh the cost of commission errors because there are few opportunities for error and so participants will frequently opt for the ‘encode and click’ strategy. Probability of cost from ‘encode and click’ is $p = 1/9 = .11$. But if the SART, for example, has two different responses categories with a 50-50 probability, then out of the 225 trials in a block each response category will be equally presented on 100 of 225 trials. The opportunity for error occurs on 25 (No-go stimuli) plus 100 (go stimuli in each response category) = 125/225 = .55 of trials if the one response option was adopted throughout. Because ‘encode and click’ will result in errors on a majority of trials, ‘encode and check’ should be adopted much of the time.

The Dual Response-Sustained Attention to Response Task

The present study explores a dual response version of the SART (DR-SART), where participants pressed one key for digits less than 5, and another key for digits greater than 5 (Go stimuli), but withheld response to the digit 5 (No-Go stimulus). There are two primary expectations of the DR-SART; the first is that it will prevent the automatization of responses thereby disrupting the feed-forward ballistic motor program. In the single response SART, the participant should have the single response in a high state of preparedness ready to react whenever a sudden onset signal occurs on the screen. In contrast, the dual response version prevents response preparation. Consequently automatized production of a pre-potent response, i.e. a commission error, is less likely in 50:50 dual response situations. Second in a dual task participants must scrutinize the stimulus and identify its numerical class (< 5, 5, > 5) in order to make a correct response choice on Go trials. Because in a random sequence the subject cannot know in advance the stimulus that will occur next, a similar degree of scrutiny must accompany No-Go stimuli, meaning that No-Go stimuli will be identified and not merely detected as sudden onset events. Again the effect of introduction of response choice is to cause a shift from ‘encode and click’ to ‘encode and check’ with resultant reduced commission errors and longer RTs.

The primary aim of the following experiments is to compare results from single and dual response versions of the SART. If the experiment yields the results expected (reduced commission errors in the DR-SART), follow up experiments manipulating the relative probability of the two Go responses become worth pursuing. The expectation is that the proportion of commission errors to the No-Go stimulus will increase with the probability of the more frequent choice alternative. This is because the pre-potency or strength of one response over another increases the greater the frequency of its use. Consequently when one response is highly likely, the relative reward for fast responses becomes greater encouraging an ‘encode and click’ strategy over an ‘encode and check’ strategy. In terms of Peebles and Bothell’s model, in a 90-10 DR-SART the more frequently occurring stimuli will be presented on 180 of 225 trials; because the more common response class occurs on such a high proportion of trials, subjects should adopt ‘encode and click’ as their predominant strategy. The opportunity for error occurs on 25 (No-Go) plus 20 (less frequent group) = 45/225 = .20 of trials. The speed benefits from ‘encode and click’ (the more common response) outweigh the costs of improbable errors.

If as predicted, commission errors in the 90-10 condition are intermediate between the standard SART and the 50-50 DR-SART, then a 70-30 version will be run as Experiment 3. In the 70-30 DR-SART the more frequent group will be presented on 140 of 225 trials. The opportunity for error occurs on 25 (No-Go stimulus) plus 60 (less frequent group) = 85/225= .38 of trials. The costs of more frequent errors outweigh the benefits of speed on relatively fewer trials and subjects should more often adopt the ‘encode and check’ strategy. Because the Peebles & Bothell model predicts that the likelihood of ‘encode and click’ is proportional to the probability of a response category, we predict that the production of commission errors by a particular responding unit will lie in order (from high to low): Single, Dual 90, Dual 70, Dual 50, Dual 30, and Dual 10.

Method

Participants

Eighty students from the University of Canterbury in Christchurch, New Zealand, participated in this study. All participants had normal or corrected-to-normal vision. The research was approved by the University of Canterbury Human Ethics Committee.

Materials and Procedure

Participants were tested in individual cubicles in a psychology laboratory at the university. They were given an information sheet and a consent form which they signed. Participants were seated approximately 50cm in front of a computer screen (377 mm x 303 mm, 1680 x 1050 pixels, 60 Hz refresh rate) that was mounted at eye level. Their head movements were not restrained. Stimuli presentation and response accuracy and timing were achieved using E-prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002).

Experiment 1

Two SARTs were used, the original SART and a dual response version of the SART (the DR-SART). Forty participants (24 female, 16 male) were assigned a subject number at random prior to undertaking the experiment, even subject numbers ran the dual response version and odd subject numbers took the single response SART. Participants ranged in age between 18 and 33 years (*M* = 21.93 years, *SD* = 3.63). Twenty participants were assigned to each version. The single response SART required participants to respond to stimuli (numbers 1 to 9) by pressing both mouse buttons to frequently-occurring Go stimuli and withhold responses to rarely occurring No-Go target (the number 5). The dual response version required participants to press the left mouse button for numbers from 1 to 4, and the right mouse for numbers from 6 to 9. The sets 1-4 and 6-9 were equiprobable. As in the single response version, responses were withheld to the number 5. Go stimuli occurred with a probability of 0.89 and No-Go targets occurred with a probability of 0.11. The tasks were each 4.3 min long and consisted of 225 trials. In each trial stimuli were presented for 250 ms, followed immediately by a 900 ms mask formed from a circle with a diagonal cross in the middle. From the off-set of the stimuli participants had a 900 ms window to register a response. Besides switching the No-Go target from 3 to 5, the single response SART was kept identical to the version run by Robertson et al. (1997). Digits varied in size and were randomly selected from font sizes of 48, 72, 94, 100 and 120 points, and were all the same font. Each session was preceded by 18 practice trails with feedback informing participants of omission and commission errors.

Experiment 2

The second experiment used a modified version of the DR-SART. The probabilities of the categories of the Go stimuli were changed from 50-50 to 90-10 for twenty participants (16 female, 4 male). Participants ranged in age between 18 and 24 years (*M* = 19.8 years, *SD* = 1.74). As in experiment 1, participants were randomly assigned subject numbers. Participants with odd numbers took a version of the experiment where the Go stimuli consisted of the numbers 1 to 4 ninety percent of the time. Conversely, participants with even subject numbers took a version of the experiment where the Go stimuli consisted of the numbers 6 to 9 ninety percent of the time.

Experiment 3

Similarly experiment 3 modified the DR-SART where the probabilities of categories of Go stimuli were 70-30 for twenty participants (13 female, 7 male). Participants ranged in age between 18 and 28 years (*M* = 20.45 years, *SD* = 2.96). As in experiment 1 and 2, participants were randomly assigned subject numbers. Participants with odd numbers took a version of the experiment where the Go stimuli consisted of the numbers 1 to 4 seventy percent of the time. Conversely, participants with even subject numbers took a version of the experiment where the Go stimuli consisted of the numbers 6 to 9 seventy percent of the time.

Results

Does the dual response requirement reduce errors of commission?

Commission errors fell from .448 in the single response condition to .186 in the dual (50-50) condition. The difference of .262, 95% CI [.152, .368] was strongly statistically significant, $t(38) = 4.987$, $p < .0001$, 2-tail (see Table 1).

Table 1 Experiment 1: mean proportion of errors and correct response times for the standard SART and 50-50 DR-SART

	Commission	Omission	Decision	Correct RT (ms)
Single	0.448	0.011		351.3
	0.192	*0.017*		*82.3*
Dual 50-50	0.186	0.018	0.057	514.2
	0.143	*0.022*	*0.036*	*51.6*
Difference	0.262	-0.007		-162.9
95% CI	.152 to .368	-.20 to .006		119 to 207

Standard deviations in italics

Conversely, Omission errors do not appear to be affected by task. The difference in omission errors between the single and dual tasks was .007, 95% CI [-.010, .020, $t(38) = .794$, $p = .432$, 2-tail. Experiment 1 provides no evidence that task (Single vs. Dual) affects omission errors. Finally correct response times were 163 ms slower, 95% CI [119, 207 ms] in the dual task , $t(38) = 7.498$, $p < .0001$, 2-tail.

In the single response SART the same response is made to all Go stimuli. In the 50-50 DR-SART the two responses are used equally often. **When one response is made much more common does the rate of commission errors increase to approximate that in the single response SART?**

We compared the single response SART, the 90-10 DR-SART and the 50-50 DR-SART. Experiment 2 provided the 90-10 DR-SART. Results indicated that commission errors in the

90-10 DR-SART were intermediate between the single response SART and 50-50 DR-SART. Therefore a 70-30 DR-SART was run as Experiment 3. Figure 3 illustrates errors in one panel and RTs in a second. The error bars are 95% CI. Figure 3 shows that commission errors increase as response uncertainty decreases. Using information metrics, (Fitts and Posner, 1967) uncertainty ranges from 1.0 in the dual 50-50, to .88 (70-30), .47 (90-10) and 0.0 in the single task. There is no uncertainty about which response to make in the single condition. The graphs illustrate that there are reliable differences in commission errors and RTs between all adjacent pairs except 70-30 and 50-50. Perhaps imbalance between the two responses has to exceed a threshold of at least 70-30 before the benefit of ‘encode and click’ exceeds the cost of the ‘encode and check’ strategy. The conclusion to be drawn from Figure 3 is that commission errors fall and RTs increase with uncertainty while response uncertainty has no effect on omissions and decision errors.

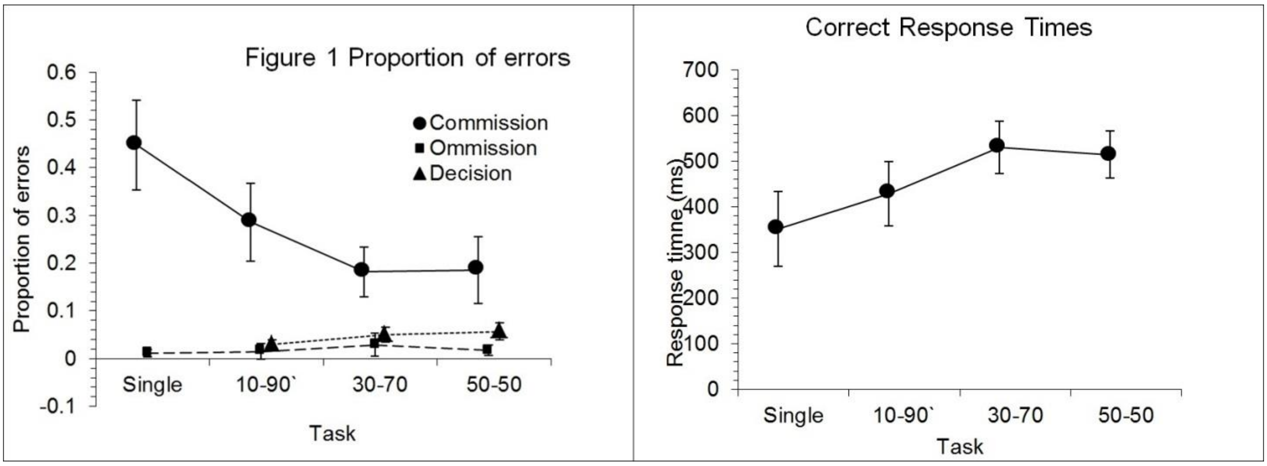

Fig. 3 Mean proportion of errors and correct response times across all conditions

Analyses so far have considered error and RTs by task. Errors and RTs have been pooled over high and low response categories. We now examine errors made separately by the finger assigned to the high or the low occurrence category (but note the actual finger used was counterbalanced across subjects). Mean proportions of errors and correct RTs for each stimulus probability along with 95% CI are displayed in Figure 4 and Figure 5 respectively. Statistical treatment of these data are made difficult because the full set of response categories over the three experiments contains a mix of between subject (e.g. 90 vs. 70) and within subject (e.g. 90 vs. 10) comparisons. Since all adjacent comparison involves independent groups, the extent of the overlap between adjacent confidence intervals can be used to indicate the statistical significance of the difference between adjacent groups.

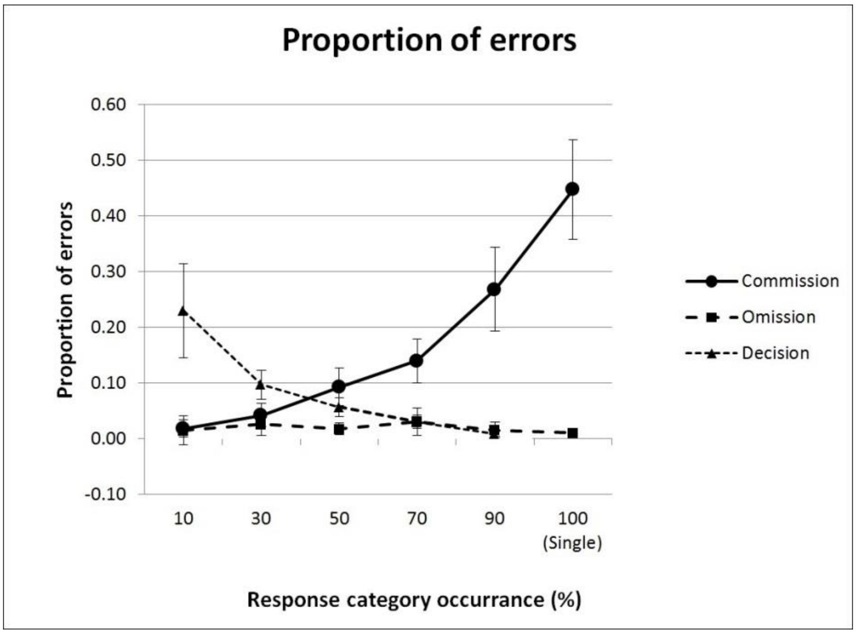

Fig. 4 Mean proportion of errors based on response category

The more frequently a responding finger is used, the higher the proportion of commission and decision errors and the faster the responses are emitted. Predominantly commission and decision errors occur when a highly common response (90 or single response) is executed quickly. Rarely does execution of an infrequent response occur to high probability stimuli. Failure to respond at all within the 1.150 second time frame (omissions) appears unrelated to frequency of use of the responding finger. If omissions occur because of lapses of attention, then lapses are independent of task conditions. Further if omission errors reflect the need to rest, then this need is independent of the frequency of use of the responding finger.

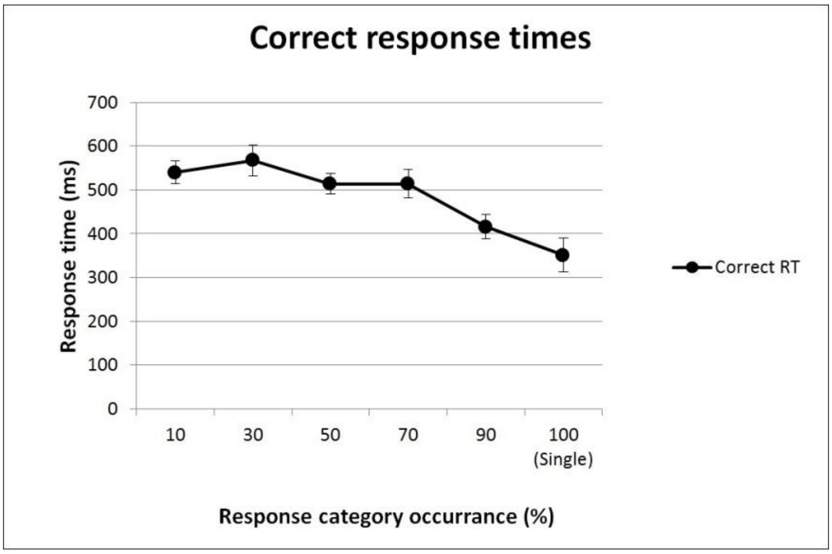

Fig. 5 Correct response times based on response category

Does making a commission error have the same consequences on following trials in dual and single response tasks?

Robertson and colleagues reported that responses prior to a correct withhold were 48 ms slower than those preceding a commission error. A similar result was found for the Single response group in the current experiment; the difference was 37 ms, 95% CI [13.9, 60.1], *t(19)* = 3.35, p = .003 2-tail (see Figure 6). Commission errors occur when prior responses are faster (encode and click strategy).

Is the consequence of a commission error adoption of an ‘encode and check’ strategy and increased reaction times? Robertson and colleagues report that response times prior to a commission error were 35ms faster than response times immediately following an error. Those results are also mirrored in the current single response experiment, response times after an error were 22 ms slower, 95% CI [7.5,36.0 ms], t(19) = 3.19, p = .005.

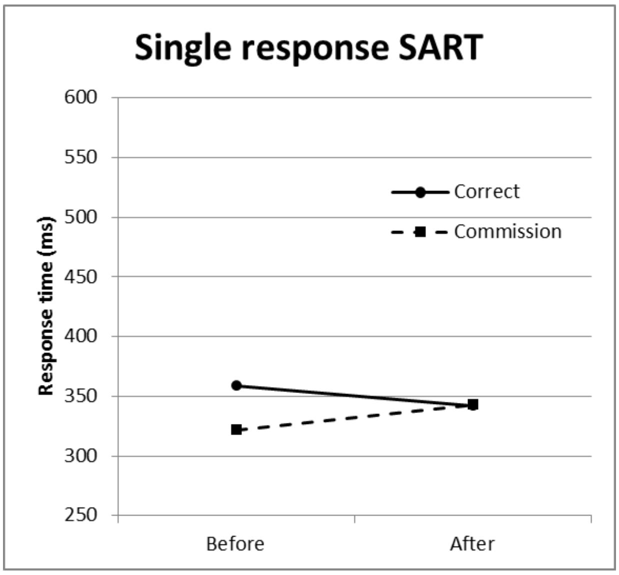

Fig. 6 Mean response times for four trials before and after commission errors and correct responses on the single response SART

A similar analysis was performed on the correct and error response times for the 50-50 DR-SART as illustrated in Figure 7. This time responses were not reliably slower prior to correct withholds than to commission errors ; mean difference 12.7 ms , 95% CI [-10.8 , 36.1], t(17) = 1.14, p = .27 2-tail. (17 df because two people made no commission errors). Perhaps the stronger requirement to check the identity of stimuli in dual task has lowered the rate of commission errors with the consequence that speed of responding is slower overall because of the need to check before making any response. However, responses prior to a commission error were faster than those following an error suggesting that response to a withhold stimulus was recognized and caused a change to a checking strategy; mean difference 43.1 ms, 95% CI [18.6, 67.7 ms], t(17) = 3.71, p = .002, 2-tail.

As can be seen in the Figure 7, responses following a decision error were slightly faster following an error, mean difference -14ms, 95% CI [-40.8, 12.9 ms], t(19) = -1.09, p = .29. So it appears that the consequences of a commission error and decision error are not the same, at least in the 50:50 DR-SART.

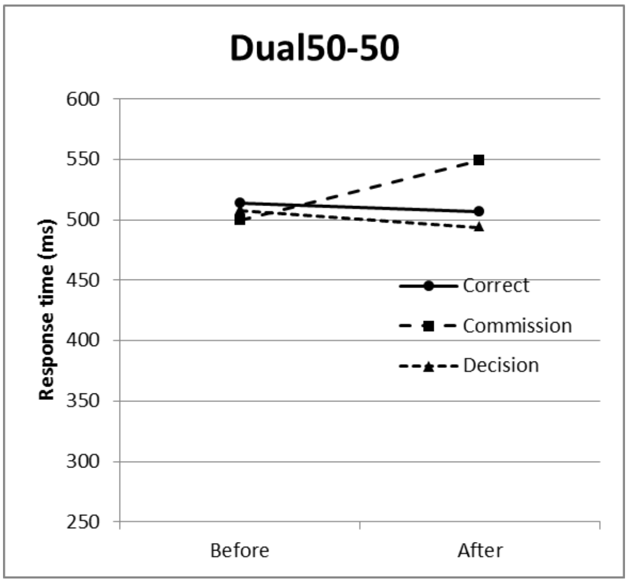

Fig. 7 Mean response times for four trials before and after commission errors, correct responses and decision errors on the 50-50 DR-SART

Turning now to the 70-30 DR-SART: RTs prior to correct withholds were 45 ms slower than those preceding a commission error, 95% CI [26.9, 63.4], $t(16) = 5.25$, $p < .001$ (see Figure 8). This result reproduces that of the Single response SART but unlike the 50:50 DR-SART. Perhaps making an error induces a shift towards the 'encode and check' strategy. RTs before an error were faster than after it, mean difference 54.7 ms, 95% CI [22.5, 86.9 ms], $t(16) = 3.60$, $p = .002$, 2-tail. (3 people made no commission errors). As in both the single response and 50-50 tasks, commission errors seem to bring about a change to 'encode and check'. Responses are slightly slower after a decision error, mean difference = 17.9 ms, 95% CI [-1.7, 37.4 ms] , $t(19) = 1.92$, $p = .071$ 2-tail.

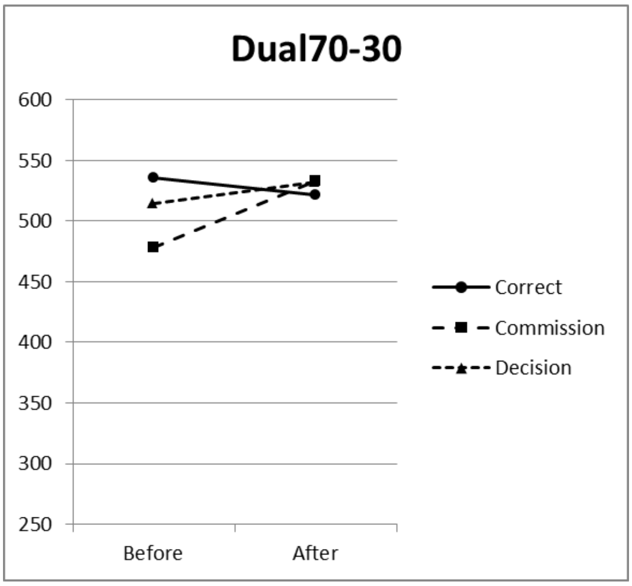

Fig. 8 Mean response times for four trials before and after commission errors, correct responses and decision errors on the 70-30 DR-SART

Finally an analysis of the 90-10 DR-SART: responses prior to a correct withhold are 34 ms slower, 95% CI =[12.2, 56.4], $t(19) = 3.20$, $p = .004$ 2-tail as they have been in all except the 50:50 DR-SART (see Figure 9). However, responses following a commission error are not slower than before the error, mean difference 2.0 ms, 95% CI [-30.3,34.2], $t(19) = .126$, $p = .901$. Commission errors do not appear to have a 'corrective' function when they occur in a dual task where one response is highly probable. Finally responses prior to a decision error do not appear to differ from those following one, mean difference 15.7 ms, 95% CI [-6.3, 37.7], $t(19) = 1.49$, $p = .152$.

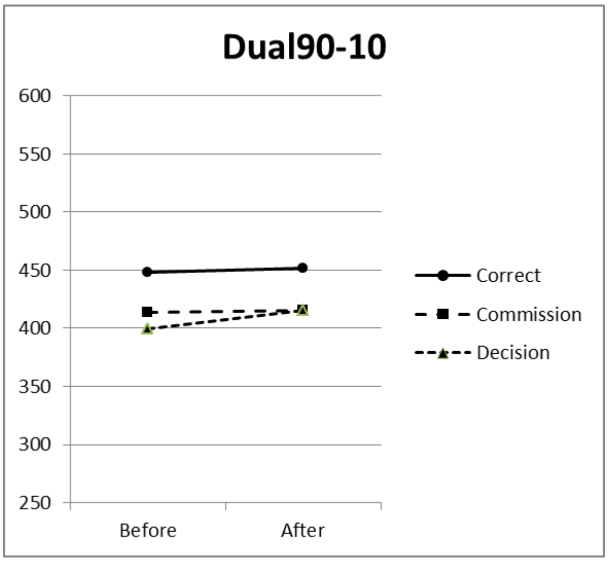

Fig. 9 Mean response times for four trials before and after commission errors, correct responses and decision errors on the 90-10 DR-SART

Overall, RTs preceding a correct withhold appear to be slower than those preceding a commission error except in the 50-50 DR-SART. This suggests that commission errors occur because people slip into an ‘encode and click’ mode until it incurs a cost except in the 50-50 where the potential for decision errors perhaps makes ‘encode and click’ always too costly. Comparison of RTS either side of a commission error suggests that people are aware they have made an error because they slow responses following such errors. This suggests it is unlikely they would have been completely mindless when they made the error or they would not have known they made one. But making a decision error does not seem to have the same slowing effect.

Discussion

The experiments reported here investigated whether modifying the SART to include a response choice would reduce commission errors. We believed that requiring a choice would lead participants to favour an ‘encode and check’ (Peebles & Bothell, 2004) strategy, due to its higher utility compared to an ‘encode and click’ strategy. As predicted, commission errors in a 50-50 response DR-SART more than halved from near 45% in the single response version of the task to around 19% in the dual response condition. This reduction was similar in the 70-30 DR-SART (18%). Further as predicted from Peebles and Bothell’s utility model the proportion of commission errors was affected by the relative prevalence of the more common response alternative. The 90-10 dual task produced commission errors that were intermediate (29%) between those of the single reponse SART (45%) and 50-50 and 70-30 (18-19%) dual tasks. This is consistent with the utility of ‘encode and click’ increasing as one response becomes far more common than the other. However, similarity of commission errors in the 50-50 and 70-30 dual tasks suggests it may be necessary for the relative frequency of the two responses to exceed a threshold level before the speed benefit from ‘encode and click’ outweighs the time costs inherent with the slower ‘encode and check’ procedure.

If a slower ‘encode and check’ procedure is adopted on a greater proportion of trials in dual conditions, then RTs to Go stimuli should be greater in the dual conditions than in the single response SART but be faster when one response is far more common. Results are broadly consistent with this prediction: single response RTs were faster than those in all dual tasks; response times in the 90-10 variant were intermediate between the single task and the dual tasks where responses were equal (50-50) or near equal (70-30). It was also possible to examine the propensity for commission errors and RTs separately for each response category (the more common and the less common) in the dual tasks. As predicted by the Peebles & Bothell model, which suggests that the likelihood of the ‘encode and click’ being adopted increases the greater the probability of a response category, probability of a response to a No-go stimulus being made by a particular finger lay in order (from high to low): Single, Dual 90, Dual 70, Dual 50, Dual 30, and Dual 10. Or in other words, the probability of a commission error being made by a particular response finger directly reflects the frequency of its use.

Turning now to decision errors, the probability that the wrong button will be pressed to a Go stimulus in a dual task appears to be inversely related to frequency of use of the responding finger. That is, generally decision errors occur because the more common response is made to rare Go stimuli. The less common response is hardly ever made to common Go stimuli. We interpret this result to imply that the relative utility of a rapid 'encode and click' outweighs the slower 'encode and check' strategy the more frequently the stimulus class. Like commission errors, decision errors are also made by the more commonly used finger; decision errors had highest probability in the Dual 10 response category when an incorrect Dual 90 response was made, followed by the Dual 30 and so on. These results indicate that commission and decision errors are driven by a common factor – response potency. Furthermore, correct response times were also faster when a more commonly used response was executed.

Omission errors are overall relatively rare and variable between people but unlike commission errors they do not appear to be affected by different response probabilities in dual response tasks or even by whether the task is single or dual response. It is claimed (e.g. Robertson et al., 1997) that response repetition induces boredom which in turn leads to disengagement and attention lapses. By this argument, lapses, and hence commission errors, should be more common in the more repetitive single response SART and the 90-10 DR SART. But if lapses are caused by the overall level of stimulus repetition they should affect omission and commission errors in a similarly. That there is no relationship between omission and commission error rates across the variations in the levels of repetition in these experiments argues against an attention lapse explanation for commission errors. Further the fact that omissions occur rarely suggests that very few lapses do occur, or if lapses do occur they are too brief to be detected in the brief response windows of these experiments.

Having to make a response choice, even when one alternative occurs on 80% of trials (Dual 90-10) has a time cost relative to a single response SART. Correct responses in the single response SART were faster than every dual condition. It would be interesting to determine whether the single response speed advantage persists when the more common response exceeds 90% or 95% of trials. With regard to frequency of response and correct RTs, the trend is for responses to be faster to the more frequent stimulus class and more so the greater the frequency difference between high and low frequency stimuli in an experiment. Additionally, we have evidence that incorrect responses occur in the DR-SARTs when the dominant response is not restrained on infrequent Go trials and on No-Go trials.

This suggests a failure to withhold a pre-potent response or to adopt an ‘encode and click with dominant finger’ strategy when there is strong imbalance between stimulus/response classes in a DR-SART.

In terms of the measurement properties of the SART

In addition to Peebles & Bothell's (2004) utility model, Cheyne et al.’s (2009) three-state attentional model of task engagement/disengagement could also provide an explanation for our results. Based on the three state model, it could be argued that instances of mind wandering increase with response potency or the adoption of the ‘encode and click’ strategy. What is required is the assumption that strength of a response (a product of its relative frequency) determines how far along the Cheyne et al. model a participant is likely to travel. In the case of the DR-SART, weaker response conditions like the Dual 10 and Dual 30 make it difficult for the participant to reach even state 1 of the model (occurrent task inattention/tuning out); reflected by the fact that weak responses hardly ever feature among commission and decision errors. The Dual 50 and 70 on the other hand would allow the participant to transition from state 1 to state 2 (generic task inattention/going through the motions). The single and Dual 90 conditions appear to carry the participant all the way to state 3 of the model -response disengagement as evidenced by the large number of commission errors present in these response categories. It could be argued that every time a commission error is made, the participant resets back to the starting point on the three state model; ‘slowly’ working their way back to state 3 and the next commission error (similar to Peebles and Bothell’s dynamic utility.

The results from the 90-10 DR-SART reveal that it is not just adding a decision component that reduces commission errors; greater frequency of a particular motor response itself results in a greater probability of error (errors of commission in the 90-10 DR-SART are significantly greater than the 50-50 DR-SART). With regard to response strategy and the speed-accuracy trade-off, Peebles and Bothell’s model provide an interpretation of our results that can account for both. The ‘encode and click’ strategy is quicker but more likely to produce commission errors; the reverse is true for the ‘encode and check’ strategy. From a response inhibition point of view, our results could indicate that the difficulty associated with inhibiting the pre-potent response is directly proportional to the potency of the response category, i.e. more commission errors/unable to inhibit a response in the single and dual 90 as illustrated by our results.

The consequences of an error

Robertson et al. (1997) explored the effects of commission errors on subsequent Go RTs by comparing RTs on the four trials before and the four trials after a correct withhold (No-Go) and similarly either side of a commission error in their SART. Results from their control subjects (without traumatic brain injury) suggested that RTs to Go stimuli decreased as trials progressed until production of a commission error led to a slowed response on the next Go trial followed by a gradual speeding of responses as trials progressed. Two findings led to this conclusion. First RTs to Go stimuli prior to a No-Go stimulus were longer preceding a correct response than preceding a commission error. Secondly RTs to Go stimuli that followed a commission error were slower those preceding it, while RTs to Go stimuli before a correct withhold were slower than those following a correct withhold. These results were replicated in the current single response SART, and DUAL 70-30 SART and partially in the 50-50 DR SART and 90-10 DR SART suggesting that even in the context of the potential for decision accuracy feedback on every Go trial a commission error still leads participants to change their strategy by reducing RTs to following Go stimuli.

Robertson et al. and others ascribe the pattern of RTs surrounding No-go stimuli to subjects adopting a more conservative response criterion, or because they inhibit automatic response to a greater degree after an error. The patterns are also consistent with the view that cognizance of an error causes a shift from an ‘encode and click’ to an ‘encode and check’ strategy but without invoking any attention processes. Change in strategy consequent upon a commission requires some level of registration that an error has been made. This in turn requires that the stimulus be identified at some level. Identification of a stimulus at a conscious level is not possible when sustained attention, as defined by Robertson et al.(1997) and Langner & Eichoff (2013), is lapsed or disengaged at the moment the stimulus is presented. That is, change of strategy following a commission error is incompatible with there being a lapse of sustained attention, but lapse of attention is used to explain the existence of the commission error. This contradiction is avoided when notions of attention are avoided, as is in the dynamic utility model proposed by Peebles & Bothell.

Perhaps surprisingly there was no similar increase in RTs following decision errors. This raises the question as to whether production of a response when none is sanctioned is in some sense more noxious than production of an incorrect response when a response is required. Alternatively, because in these experiments multiple stimuli were mapped to each Go response, and the stimuli did not inherently denote which finger to respond with, decision errors may not have been immediately and sufficiently obvious to result in a change of strategy.

Those who have been critical of the validity of the SART as a measure of sustained attention seem to overlook what Robertson and colleagues found in their initial work. Normal control participants slowed down after making a commission error, they learnt from their mistakes. To do that, normal subjects must have registered of the stimulus's identity. There was no stimulus decoupling with them. In fact, as Robertson and colleagues explain, a pre-potent motor response was set up, but to keep it under control they had to pay attention to stimulus identity, and they did because they corrected their strategy following a commission error. The TBI patients however, did not slow down following a commission error. They did not learn from their mistakes. One reason could be that they may not have registered stimulus identity because they were unable to sustain attention in which case the SART can be a valid measure of sustained attention after all. Studies questioning the validity of the SART as a measure of sustained attention have not explored how TBI (or other groups) behaved in their variants of the task.

Consider the nature of the SART. The subject has to respond to every digit except one. The same response is made to 8 out of 9 of the stimuli which also vary in font size. The subject is instructed to respond as quickly as possible. In this context it is reasonable to suppose that an intelligent subject will try to find features that are common to all Go stimuli. All Go stimuli share one property: sudden onset, which is known to be a strong attractor of attention (Yantis, 2005). Consequently it is reasonable to suppose that subjects link response production to any sudden onset event, disregarding variations in their identity. Because No-go stimuli are relatively rare, commission errors occur. By this argument the commission errors do not necessarily result from lapses in sustained attention. In one sense the subject never attends to the stimulus, in another sense the subject always attends to one property of the stimulus, its sudden onset. But normal subjects do attend to stimulus identity, because they slow down following an error. TBI patients also attend to the common feature of the stimuli (their sudden onset), otherwise they would not respond at all to the Go stimuli and they would make very large numbers of omission errors, which they don't. Consequently even TBI patients must be sustaining their attention in some way. What TBI patients do not do is to alter their behaviour when they do make an error. The important question is why they don’t alter their strategy following an error. Although our experiments establish strongly (as Robertson et al. supposed) the importance of a pre-potent response in Go No-Go situations and while they also support a viable non attention explanation for the occurrence of commission errors and RT patterns surrounding No-Go stimuli, they don’t address why individuals with TBI’s fail to learn from their mistakes.

Future experiments could fill out the DR-SART series with 80-20 and 95-5 or even more extreme response probabilities. Responses can be speeded overall by using more response compatible stimuli such as left and right pointing arrows for left and right responses, with a double headed or no headed arrow (line) as the No-Go stimulus. In the SART many different stimuli are mapped to a single response (8 to be precise). The participant searches for what is common to them all – sudden onset and uses that as the cue to produce a response. If this is true, reducing the stimulus set to just two very clearly discernible stimuli (e.g. large red circle, vs. small blue triangle) should reduce the incidence of commission errors greatly. On the other hand, if it is the pre-potence of a response that drives commission errors, using such saliently different stimuli should have little effect. It is also possible that sudden onsets (in natural settings these would signify object movement) inherently capture attention (e.g. Yantis, 2005) and fire a pre-potent response. Therefore manipulations where stimuli inset was gradual may reduce commission errors. Gradual onsets could be achieved by displaying stimuli pixel by pixel or by gradually increasing contrast of their contours.

In conclusion, the DR-SARTS along with Peebles and Bothell’s model provide an explanation in terms of utility, that has no place for attention or mind wandering etc. but is able to account for the results and therefore presents a viable challenge to explanations of commission errors in the broader family of Go – No-Go tasks. Additionally, the rarity of omission errors and their independence of response strength variations suggest that attention lapses, if they occur are of less duration than the response window in these experiments.

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