Friendly fire and the Sustained Attention to Response Task:

Using basic laboratory research to investigate a real-world problem

A thesis submitted in partial fulfilment of the requirements for the

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ABSTRACT

The primary aim of this thesis was to investigate whether the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), a high Go, low No-Go response task, may provide an empirical model of friendly fire accidents in some battle scenarios. A growing body of evidence suggests that rather than sustained attention failures, errors of commission in the SART are due to failures of response inhibition or response strategies. Some friendly fire accidents may also be due to failures to inhibit a motor response rather than commonly-cited factors such as mistaken identity. In recent times, soldiers often share battle spaces with foes but also allied soldiers and non-combatants (e.g., civilians). Engagements are at close range and extremely fast-paced, and therefore it is imperative to fire weapons not only accurately, but quickly too. These conditions share important characteristics with the SART and as such some modern battle environments may give rise to the same sort of behaviour seen in the SART. That is, people have difficulty withholding responses to rare No-Go (or friendly) stimuli in situations where there are a high proportion of Go (or foe) stimuli. Six experiments were conducted to explore whether failures of response inhibition may contribute to some friendly fire accidents. Firstly, relatively applied paradigms that incorporated characteristics of the SART into simulated battle scenarios were conducted. The same behaviours that are commonly seen in the SART, namely speeded responses to Go stimuli (foes) and frequent failures to withhold to No-Go stimuli (friends), were evident in the battle scenarios. Following this a more basic experimental approach was taken to examine the underlying mechanisms of performance, using several modified computer-based SARTs. This also presented the opportunity to explore how additional factors that might be relevant to combat might affect response inhibition. Firstly, as the proportion of foes in a battle scenario surpasses two-thirds, the likelihood of response inhibition failures (e.g., friendly fire) appears to increase markedly. Secondly, decreasing the physical or manual requirements to execute responses—such as automated weapons systems often do—may exacerbate failures of inhibition. Thirdly, stress or anxiety, a common response during combat, appears to further impair an individual's ability to withhold responses. The current thesis suggests that the likelihood of response inhibition failures (e.g., friendly fire) may increase in battle scenarios where soldiers confront a small proportion of friends or non-combatants amongst a high proportion of foes. Additionally the findings provide further evidence that commission errors in SART-like tasks are primarily due to response inhibition failures or response strategies, as opposed to perceptual decoupling. Despite the SART's artificial appearance, it has been used here to uncover new contributing factors to a deeply applied problem. This thesis also further reinforces the relevance of basic research for understanding complex real-world problems.

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1 Introduction

1.1 Friendly fire

Blue on blue, friendly fire, or the more commonly used term in military contexts, fratricide, has been defined as “the employment of friendly weapons and munitions with the intent to kill the enemy or destroy his equipment or facilities, which results in unforeseen and unintentional death or injury to friendly personnel” (U.S. Department of the Army, 1993, p.1). Friendly fire has a long history. For example, in the French and Indian wars of 1758, two separate British detachments mistakenly fired upon each other due to poor visibility, which resulted in casualties (Doton, 1996). Some say that friendly fire is an inescapable cost of combat (Marine Corps University Command and Staff College, 1995) while others argue that improving understanding of the underlying human factors involved in these accidents can reduce fratricide rates (Greitzer & Andrews, 2008; Wilson, Salas, Priest, & Andrews, 2007).

Friendly fire can occur among modern-day warfighters for multiple reasons, such as the higher fire rates of modern firearms and difficult environmental conditions (e.g., night-time operations). Cognitive factors, such as expectancy bias (Greitzer & Andrews, 2008), increased cognitive load (Scribner, 2002), and shared cognition across teams (Wilson et al., 2007) have been implicated too. Emotional states may also have an impact on the likelihood of friendly fire. Combat environments typically present a multitude of highly negative stimuli and adverse experiences, and can be extremely stressful for the individuals involved. Proximal stressors may include concussive force from blasts, involvement in intense small-arms firefights, witnessing comrades being wounded or killed (King, King, Vogt, Knight, & Samper, 2006), or watching close-up high-definition footage of violent explosions and their aftermaths, as in the case of unmanned vehicle operators (Fitzsimmons & Sangha, 2012). Distal stressors, such as worries from home, are also common (King et al., 2006). Urban combat, or military operations in urban terrain, are becoming more and more common (Davis, 2015; Glaze, 2000) and appear to present the most stressful environments of all. Battles are fought at close quarters, soldiers can have difficulty concealing themselves, and identifying which people are hostiles can be unclear (Helmus & Glen, 2005). Stress can affect a variety of characteristics in the modern-day soldier, such as energy levels, decision-making, speed of reactions, and memory (Moore, Mason, & Crow, 2012). The impacts of stress can be positive or negative. Its impact on the likelihood of friendly fire is not currently clear (Helton, Kern, & Walker, 2009a).

Friendly fire rates have steadily increased since the Second World War (Rasmussen, 2007) and friendly fire is estimated to account for between 10% and 24% of all allied-force casualties (Gadsden, Krause, Dixson, & Lewis, 2008; Schraagen, te Brake, de Leeuw, & Field, 2010). Ground-to-ground combat seems to present the highest opportunity for fratricide, with 69% of friendly fire incidents during the Desert Storm operation involving ground-to-ground engagements (US Congress, Office of Technology Assessment [OTA], 1993). Rates of civilian casualties, or collateral damage, are more difficult to gauge and as a result many statistics do not include them. Furthermore, friendly fire incidents often go unreported (Stevenson, 2006). This is likely due to the effort involved in investigating them and the far-reaching negative consequences that these accidents often have (Hart, 2004). Aside from the obvious loss of life and injury, friendly fire can affect friendly forces by reducing confidence, cohesion, morale, and causing soldiers to become dangerously hesitant (McNew, 2008; Rasmussen, 2007). Such incidents also attract negative media attention, often leading to a loss of public support for international peace-keeping efforts (Hart, 2004; Shrader, 1992).

Following the most recent friendly fire incident the New Zealand Defence Force was involved in, there was a risk of a public backlash. In August 2012, two New Zealand soldiers were hit by friendly fire in the Battle of Baghak, in Afghanistan. New Zealand forces had been assisting Afghan special police when they were ambushed by insurgents in a valley. In the confusion that ensued, Lance Corporals Pralli Durrer and Rory Malone sustained fire from a gun atop a New Zealand light armoured vehicle (Small & Watkins, 2013). While peace keeping operations are often criticised, failing to engage in these operations can lead to far greater consequences, such as genocide. One of the United Nations' principles of peace keeping is that force is used only in self-defence. Unfortunately, force is sometimes necessary to resolve conflict.

The introduction of new weapons with higher rates of fire and improved accuracy has increased the likelihood of friendly-fire incidents, particularly for those where both the victims and the sources are on the ground (ground-to-ground). Further contributing to this likelihood is a higher proportion of joint operations, increased speed of ground operations, and more frequent operations in urban terrain at close quarters (Hart, 2004). Close quarters, or short range combat, presents the highest risk for the accidental shooting of allies or non-combatants (U.S. Department of the Army, 2003).

While forces are now more mobile than ever, one of the downsides of this is that forces are more often dispersed, contributing to difficulties in knowing where allied soldiers are, or poor situation awareness (Defense Science Board, 1996). A further challenge is that enemy combatants often deliberately inter-mix with civilians (McDermott, Battaglia, Phillips, & Thorsden, 2001). This has been the case in Iraq, where insurgents have been known to take civilians hostage and use them as body shields, further compounding the risk of accidental shootings (Chang, 2007). It is troubling that urban operations are increasing in frequency and this is expected to continue as urban populations rise (Davis, 2015).

Attempts to mitigate friendly fire have been documented from as early as 1777. In the Battle of Germantown, General George Washington instructed soldiers to attach pieces of paper to their hats to help prevent British allied forces from mistaking them for the enemy in the fog (Ward, 1952). Simple methods like this are still in use today, for example, allied forces sometimes paint markings onto their vehicles so that pilots can more readily identify them from the sky (Wise, 2011). The effectiveness of this is debatable however, partly because such markings are also visible to opposing forces.

Recently, research has focused on technological countermeasures, such as the blue force tracking system (BFT; Armenis, 2010; Ho, Hollands, Tombu, Ueno, & Lamb, 2013) and rifle-mounted identification friend-or-foe (IFF) aids (Cruz, 1996; Seah & Deepan, 2012). BFT systems provide soldiers with a digital map showing the positions of allied soldiers based on global positioning system technology (GPS) information, while IFF systems are designed to interrogate a potential target and then indicate to the user whether the target is a foe or not. However, problems arise when reliability is less than perfect with these systems, which is often the case (Dzindolet, Pierce, Beck, Dawe, & Anderson, 2001; Kogler, 2003; Parasuraman & Riley, 1997). Urban terrain often leads to “dead spots” where BFT system information is compromised due to signal interference from nearby buildings or structures. Bryant & Smith (2013) found that the use of BFT with 10 second lags or delays (which is typical of BFT; see Suri et al., 2009) led to significantly more friendly fire accidents, regardless of whether participants were forewarned about the delay or not. IFF aids may also be less useful in fast-paced engagements; the time required for the IFF system to interrogate a target and then return a value delays soldiers’ reaction times (Allegretti, 2000; Kogler, 2003), which can give an enemy more time to fire first. Furthermore, these technologies are unable to classify non-combatants or foes. For example, IFF aids return a value of “friend” or “unknown” to the user of the system, requiring the user to determine whether an unknown target is an enemy combatant or a non-combatant (or in rarer cases, an ally using a malfunctioning IFF transponder). The ambiguity of this information can be problematic (Karsh, Walrath, Swoboda, & Pillalamarri, 1995). Complicating matters further is that enemy forces may be able to spoof IFF sensors, causing the sensor to return a value of “friend” instead of “unknown” (Committee on Defense Intelligence Agency Technology Forecast, 2005). Aside from these issues, technological devices can be damaged during operations, lost, misused, or not used at all in the case of coalition forces who have either do not have it or have incompatible systems (Dzindolet et al., 2001; Kogler, 2003).

When considering approaches to mitigate friendly fire accidents, human factors is thought to be the least-well-understood area as well as the area for which more research could provide the most significant cost/benefit outcome (Gadsden et al., 2008). Currently, for example, it is not clear whether loss of inhibitory control is a contributing factor in some friendly-fire incidents (Greitzer & Andrews, 2008). Certain scenarios may cause shooters to be highly reactive to the emergence of targets. For example, fast-paced, close quarters engagements, conducted in “target rich” environments may lead to a potential problem of soldiers being unable to withhold a pre-potent (e.g., automatic and requiring suppression or inhibition) fire response (Helton, Kern, & Walker, 2009a). If soldiers are engaged in a firefight in a cluttered urban environment where they are confronted by many enemy combatants embedded within relatively few non-combatants and comrades (e.g., a target-rich environment), they may have difficulty inhibiting their responses to shoot when a comrade or non-combatant appears, particularly when they were expecting to confront a foe instead. Indeed, Helton and colleagues (Helton & Kemp, 2011; Helton, Weil, Middlemiss, & Sawers, 2010) have suggested that this process may already be modelled empirically in the psychological laboratory with the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997).

1.2 The Sustained Attention to Response Task (SART)

The Sustained Attention to Response Task (SART; Robertson et al., 1997) is a Go/No-Go response task originally developed to assist the diagnosis of traumatic brain injury (TBI) patients with sustained attention deficits. Sustained attention, or vigilance, describes the maintenance of attention over periods of time. Sustained attention has considerable importance in settings such as air traffic control (Hitchcock et al., 2003), military surveillance (McBride, Merullo, Johnson, Banderet, & Robinson, 2007), medical device monitoring (Gill, 1996), operating automated vehicles (Neubauer, Matthews, Langheim, & Saxby, 2012), agricultural inspection tasks (Hartley, Arnold, Kobryn, & MacLeod, 1989), train driving (Edkins & Pollock, 1997), and the piloting of both manned aircraft (Wiggins, 2011) and unmanned aircraft (Tvaryanas, 2006). The SART is frequently used in clinical settings to diagnose sustained attention deficiencies in patients with TBI (Chan, 2001; Manly et al., 2004; O'Keeffe, Dockree, & Robertson, 2004; Robertson et al., 1997), attention deficit hyperactivity disorder (Dockree et al., 2004; Greene, Bellgrove, Gill, & Robertson, 2009; Johnson et al., 2007), depression (Farrin, Hull, Unwin, Wykes, & David, 2003; Smallwood, O'Connor, Sudberry, & Obosawin, 2007) and many other pathologies (Chan et al., 2009; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; O'Connell, Bellgrove, Dockree, & Robertson, 2006; Seok et al., 2012).

The SART differs from traditional vigilance tasks. In traditional tasks, subjects are required to respond to infrequent target, signal, or "Go" stimuli, which are embedded amongst frequent distractor or "No-Go" stimuli. In other words, these are "low Go, high No-Go" tasks. In the SART though, this format is reversed, with subjects instead instructed to respond to the more frequent Go stimuli and withhold responses to infrequent No-Go stimuli (a high Go, low No-Go task). Whereas the targets in traditional tasks require responses, in the SART, the rare target which subjects are searching for is a No-Go stimulus which requires participants to instead withhold responses. Stimuli in the SART occur at regular, short intervals (typically 1–2 seconds) with Go and No-Go stimuli being randomly intermixed with each other.

Robertson and colleagues (1997) developed the SART primarily because at the time they felt current measures of sustained attention were inadequate and attention deficits in TBI patients were not sufficiently characterised. Furthermore, the long duration of traditional vigilance tasks can be inconvenient for neuropsychological assessments and other performance batteries. The primary performance metrics on the SART are errors of commission (failures to withhold responses to No-Go stimuli) and response time to Go stimuli. Errors of omission (failures to respond to Go stimuli) are also examined, although these typically occur at a much lower rate in the SART.

SART performance demonstrates a classic speed–accuracy trade-off. Subjects who respond faster to Go stimuli tend more often to inappropriately respond to No-Go stimuli (a commission error). The speed–accuracy trade-off has been observed many times in the SART (Helton, 2009; Helton, Head, & Russell, 2011a; Helton et al., 2009b; Ishimatsu, Meland, Hansen, Kasin, & Wagstaff, 2016; Peebles & Bothell 2004; Robertson et al., 1997) and has been attributed to a self-organising feed-forward ballistic motor program (Head & Helton, 2013, 2014; Helton et al., 2010). When several Go stimuli occur in a rapid sequence, the Go motor response becomes pre-potent and requires active and deliberate control to inhibit. When an infrequent No-Go stimulus appears, participants are often physically unable to inhibit the motor response routine in time and thus make an error of commission (Head & Helton, 2012, 2013; Peebles & Bothell, 2004; Stevenson, Russell, & Helton, 2011).

There is currently debate over whether the SART is in fact an adequate measure of sustained attention. From one perspective errors on the SART index lapses of attention. From another perspective however SART performance is influenced more by other psychological processes, such as response inhibition and simple response strategies. While the creators of the SART acknowledge that the speed–accuracy trade-off and response inhibition are factors within SART performance, they have downplayed their contribution. A key point of contention exists within the literature, regarding what actually causes the trade-off and errors of commission in the SART.

1.2.1 What does performance on the SART actually measure?

1.2.1.1 Mindlessness, mind wandering, or perceptual decoupling

From one perspective, the monotonous nature of SART stimuli and the task itself causes participants to become disengaged from the task, or perceptually decoupled. The requirement to respond to frequent Go stimuli supposedly lulls participants into an automatic pattern of responding which requires little effort to maintain (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson et al., 1997). This perceptual decoupling from the task is thought to result in a failure by participants to identify No-Go stimuli when they occur, thus leading to commission errors. From the perceptual decoupling perspective, speeded response times and commission errors are due to external attentional failures or failures to perceive the stimuli.

1.2.1.2 Motor inhibition and response strategies

Many researchers (e.g., Carter, Russell, & Helton, 2013; Dillard et al., 2014; Head & Helton, 2013, 2014; Helton et al., 2005, 2009, 2010) disagree with the perspective that commission errors in the SART, and the speed–accuracy trade-off, are the result of absentmindedness and perceptual decoupling.

Evidence that the SART does not promote mindlessness includes: (1) Participants report high mental workload on the NASA-Task Load Index scale (Grier et al., 2003); (2) Reported task-related thoughts are high in the SART (Carter et al., 2013); (3) Participants can detect subtle changes in spatial and temporal elements of the No-Go stimuli appearances (Helton et al., 2005, 2010); and (4) Participants are aware of the commission errors they make 99.1% of the time (McAvinue, O'Keefe, McMackin, & Robertson, 2005).

Proponents of this alternative view suggest that the SART is being used incorrectly. From their perspective, SART performance is the result of various psychological processes, including motor response inhibition and response strategies used by participants. The requirement to frequently make rapid responses to Go stimuli leads to the development of a pre-potent motor response routine (Head & Helton, 2013, 2014; Helton et al., 2010). When a rare No-Go stimulus occurs, participants are often physically unable to inhibit the motor routine in time and consequently make a commission error. Peebles & Bothell (2004) demonstrated how an Adaptive Control of Thought-Rational (ACT-R; Anderson & Lieberman, 1998) model is able to predict the association between response times to Go stimuli and probability of errors of commission. In this model, two competing response strategies are described which can explain the speed–accuracy trade-off in the SART:

1. Encode and click: Immediately after stimulus detection the participant *clicks*. This is the fastest strategy but comes with the cost of increased commission errors.

2. Encode and check: After stimulus detection the actual identity of the stimulus ("Go or No-Go?") is *checked*, before a click response is made or withheld.

The encode and click strategy maximises speed, which 89% of the time (typically 89% of stimuli are Go stimuli) is an effective strategy in the SART. Conversely, the encode and check strategy slows responses to all stimuli as it requires participants to verify stimuli identity on all trials. While this strategy is slower, it usually enables participants to withhold to No-Go stimuli on the rare occasions that they appear. The strategy choice is dynamic. Choice between encode and click and encode and check changes from trial to trial depending on a quantity called "utility."

$$U_i = P_iG - C_i + \sigma \qquad (1)$$

In equation 1 (above) taken from Peebles and Bothell (2004), U_i is the utility value of a strategy. P_i represents the probability of success when using that strategy and is reflected by the previous successes and failures experienced with that strategy. G is a parameter representing the cost of the current goal and C_i represents the cost of adopting that strategy until the goal has been achieved. The costs of both G and C_i are measured in time. Finally, σ represents a noise value. The amount and type of errors that a participant makes will determine how much utility each strategy has at any one time. For example, after a fast correct Go response, the utility of encode and click is enhanced, whereas after an incorrect No-Go response (commission error), the utility of encode and check is boosted. Given that the SART is a high Go task (most of the time the correct response is to click), the encode and click strategy is often preferred by participants. Note that for the sake of simplicity, the "utility" of the strategy choice will be hereafter referred to as "usefulness."

Many aspects of SART performance can be explained without invoking concepts such as mindlessness, mind wandering, or inattention. Studies show that SART performance is heavily influenced by top-down factors. Simply changing the task's instructions to emphasise accuracy over speed leads to slower responses and fewer commission errors (Seli, Cheyne, & Smilek, 2012). Increasing the time required to execute responses, by extending the physical response movement required, also lengthens response times and reduces commission errors (Head & Helton, 2013, 2014), as does making the location of stimuli uncertain (Head & Helton, 2014). Requiring participants to respond in time to a delayed audible chime reduces commission errors (Seli, Jonker, Solman, Cheyne, & Smilek, 2013). Subtly changing the timing of No-Go stimuli presentation throughout the task leads to fewer commission errors, suggesting participants are attentive to the stimuli (Helton et al., 2005). Participants often anecdotally report that they frequently responded to No-Go stimuli despite realising fractions of a second before they pressed the button that they should not do so. They report being unable to control their hands on these occasions. This has been referred to as "alien hand syndrome" (Cheyne, Carriere, & Smilek, 2009). When participants are given warning cues that predict the onset of No-Go stimuli, they use these to their advantage and show reduced commission errors and shortened response times, further indicating their attentiveness to the task (Finkbeiner, Wilson, Russell, & Helton, 2015; Helton, Head, & Kemp, 2011a; Helton, Head, & Russell, 2011b;). Additionally, stimuli that are novel or engaging fail to improve performance compared to boring or repetitive stimuli (Finkbeiner et al., 2015; Head & Helton, 2012). In sum, there is a wealth of evidence against the strict perceptual decoupling perspective. It appears that participants do indeed perceive the stimuli, but are unable to withhold their response. From a personal perspective it is as if their hand is operating independently of conscious control.

The debate about what the SART actually measures is much more than just a theoretical issue though. Firstly, the SART has been and continues to be used as a diagnostic aid for TBI in clinical patients, and to indicate sustained attention deficits in a range of other clinical populations. In a context where people's quality of life may be affected by interventions (or the lack of them) following diagnostic tests, it is not acceptable that the diagnostic tool lacks validity. Secondly, if the SART is, as many suspect, more a measure of ability to exercise inhibitory control than sustain attention it may prove valuable in understanding real-world behaviours where response inhibition plays a role. Battlefields and friendly fire accidents could be one such context where response inhibition is crucial. However, whether a simple or "basic" artificial laboratory task such as the SART could actually be used to investigate such an applied problem as friendly fire is itself unclear. A secondary motivation for the work reported in this thesis is that basic laboratory research, no matter how artificial in appearance, may have significant implications for complex real-world problems.

1.3 Basic versus Applied Research

Within human factors psychology and sciences in general, a distinction is often made between "basic" research and "applied" research. Basic research typically involves experimental research conducted in controlled laboratory environments. Potentially confounding variables can be rigorously controlled in order to precisely measure the effects of manipulations of the variables of interest. Within cognitive psychology, basic research is often used to investigate microcognitive constructs, such as sustained attention, working memory, and response inhibition. On the other hand, applied research often involves more naturalistic research, for example observations of skilled workers within their actual work contexts. Applied research is particularly useful for exploring macrocognitive constructs, such as coordination, sense-making (Klein et al., 2003), and naturalistic decision making (although see Boyes & O'Hare, 2011, for an example of basic research used to investigate naturalistic decision making).

Some believe that basic research is not useful for understanding real-world behaviours. Criticisms include that basic research is too artificial, lacks ecological validity, and is driven by the "idle curiosity" of academics, rather than problems or opportunities in the real-world (see Helton & Kemp, 2011, for an in-depth discussion on this). Helton & Kemp note how modern psychology textbooks often neglect to discuss psychology's highly practical and technological origins, further contributing to this school of thought. Concerns over the ecological validity of psychological laboratory research are not new however (Wilson, Helton, & Wiggins, 2013a). For example, Brunswik (1957) was highly critical of cognitive psychology for focussing too heavily on the organism (e.g., the human) at the expense of the surrounding environment.

However, many examples demonstrate that basic research is as crucial to solving real-world problems as applied research is. For instance, by using a joint application of these two approaches, Norman

Mackworth was able to understand the applied problem of Air Force radar operators' performance declining over prolonged periods of monitoring. Mackworth created an extremely artificial laboratory task called the clock task (1948). Participants were tasked with monitoring the seconds hand on a clock face and detecting the rare occurrences of it moving irregularly, by jumping not one second ahead but two. To someone who initially had no knowledge of the clock task's application to understanding Air Force radar operator performance, the task would seem obscure and irrelevant to anything in real-life. Mackworth realised that the clock task provided a means to test, in the psychological laboratory, the same construct that was responsible for the decline in radar operator's performance—vigilance. Using a basic approach enabled Mackworth to understand the underlying psychological mechanisms of this applied problem. The enhanced level of understanding enabled the Air Force to make important improvements to their operational procedures. Another classic example is Colin Cherry's empirical research into how people understand auditory messages received by one and two ears (Cherry, 1953). His work helped to address a problem commonly experienced in air control towers in the 1950's, whereby controllers had difficulty attending to messages from multiple pilots at once, whose voices were often broadcasted over a single loudspeaker in the control tower (Eysenck, 2004).

The SART is the epitome of a basic, traditional, laboratory computer task. There is unlikely to be any situation in real life where people monitor a computer screen for digit stimuli, responding to 89% of the digits and withholding to the remaining 11%. The SART's artificial appearance may lead people to think that it cannot possibly be useful for understanding any real-world behaviours, especially behaviour in such an applied and complex environment as a battlefield. By using the SART to investigate friendly fire, this thesis will also reinforce the importance of basic research to exploring complex and challenging real-world problems.

1.3.1 Using the SART to understand Friendly Fire

While the SART may appear to be an artificial task that is removed from much in the "real world," it may actually be a useful vehicle for studying behaviour in some operational contexts. As Helton & Kemp (2011, pp. 404) said:

> *"The link between investigating pre-potent actions in the laboratory under controlled conditions and understanding the failure to inhibit pre-potent actions appropriately in the real world is in the eye of the beholder."*

Helton and Kemp suggested that the SART could be used to examine action slips (or unintended actions; see Norman, 1981) in real world contexts. For example, increasing levels of automation could make system operators more vulnerable to committing response inhibition errors. Automation often reduces the manual or physical input required of human operators, frequently leading to more rapid processes but potentially conditions that are prone to error. In many ways, automated tasks are beginning to resemble the SART. Take the example of automated weapons systems where operators are often seated at a computer which they use to control weapons remotely. Many of these systems can detect and aim at targets themselves and may only require the human operator to click a button to fire. Operators may have little time in which to deliberate over a possible target (Egeland, 2004). This process is not much different to monitoring a screen for digit stimuli and pressing a spacebar to respond, as in the SART.

Modern battlefields may also bear similarities to a computer-based SART, particularly for ground operations where battles are fought at close-quarters. For example, dismounted soldiers confront foes but also allies and civilians, all of which they must correctly classify as shoot or no-shoot targets within very short spaces of time. In a SART, participants monitor displays for rapidly-presented stimuli which they must correctly classify as Go or No-Go stimuli. The similarities between the SART and a battlefield are particularly evident for military operations in urban terrain. This is because, firstly, enemy and friendly forces, as well as non-combatants (e.g., civilians) tend to be intermixed in the same areas (McDermott et al., 2001). Thus there is a high chance of encountering allied soldiers or civilians in locations where foes may also be. Secondly, target acquisition occurs at a much faster pace than on traditional battlefields (U.S. Department of the Army, 2011). Soldiers are under pressure to engage targets rapidly.

Failures of inhibitory control could be contributing to some friendly fire incidents. The SART may provide an appropriate, although simplified, empirical model in the laboratory for some battlefield environments (Helton et al., 2010; Helton & Kemp, 2011). This could especially be the case when the makeup of the environment resembles the relative Go to No-Go proportions in the SART. For example, an environment that contains a large proportion of enemy combatants (e.g., Go stimuli) intermixed with a small proportion of allied soldiers and/or civilians (e.g., No-Go stimuli) is similar to a SART which requires participants to respond to a high proportion of Go stimuli and withhold to the small remaining amount of No-Go stimuli. In the SART, this frequent nature of responding leads to the development of a pre-potent motor program. As a consequence, participants often fail to withhold responses to the No-Go stimuli.

Some friendly fire accidents that may have been classified as failures of perception or mistaken identity could actually instead be due to the same type of errors that are seen in the SART; that is, failures of response inhibition. Integrating characteristics of the SART into simulated combat scenarios could provide a means to test this. SART-like tasks have not yet been examined in a more realistic firearm simulation using actual moving humans as Go and No-Go stimuli, that is, foes (Go stimuli) and "friendlies" or civilians (No-Go stimuli). This will be addressed in the current investigation.

1.4 Overview of this thesis

The majority of chapters are based on separate, self-contained articles or proceedings that are either published or have been submitted. These are reproduced in the various chapters. To ensure clarity of the links between each chapter as well as the overall message conveyed in this thesis, for each of the chapters containing articles (Chapters 2–7) a "rationale" section has been included at the beginning and a "summary" has been included at the end.

1.4.1 Performance Metrics

Experiments involving modified versions of the SART are present within each of the Chapters 2–7. Hypotheses were formulated and then assessed through the recording of both behavioural and subjective measures. Behavioural measures were typically rates of commission errors (responding to the No-Go stimuli), omission errors (failing to respond to the Go stimuli), and response time to Go stimuli. Subjective measures included self-report questionnaires and scales which assessed thought content, mood, emotions, and arousal levels.

1.4.2 Layout

Chapters 2 and 3 use a relatively applied approach to explore whether response inhibition errors, like those that occur in the SART, may occur in some combat scenarios. Chapter 2 explored whether some friendly fire accidents occurred because of response inhibition failures rather than person misidentification. A simulated battle scenario was created where the proportions of foes to friends was manipulated. In Chapter 3, the applicability of the SART as an empirical model for friendly fire accidents was further tested by using a different simulated firearms task to the one used in Chapter 2. Whether or not speed–accuracy trade-offs (like those that occur in the SART) occurred for people using firearms was examined. The simulated firearms task in Chapter 3 employed a more controlled experimental paradigm and participants also completed traditional computer-based versions of the SARTs.

After demonstrating in Chapters 2 and 3 that response inhibition errors appear to occur in firearms operators too, Chapters 4–7 investigate why response inhibition errors occur as well as what contributing factors or characteristics further exacerbate these errors. In particular, characteristics that are highly relevant to modern armed combat were explored, namely: the proportion of No-Go stimuli (friends) to Go stimuli (foes) in an environment; the level of automation weapons have; and the experience of anxiety or stress. Chapter 4 further examined the impact that the relative proportion of Go to No-Go stimuli has on performance. Computer task versions of the SART with four different proportions of Go stimuli were used (.50, .65, .80, and .95). A thought measure questionnaire was also administered. In Chapter 5, the effect of artificially delaying responses in the SART was investigated by manipulating the manual movement required to execute responses. This also allowed the possible impact of increasingly automated weapons systems on friendly fire rates to be explored. Subjective thought measures provided insight into whether performance changes resulting from the movement manipulation were due to perceptual or physical factors. In Chapters 6 and 7, modified SARTs were used to explore the effects of anxiety on commission error rates. This provided potential insight into the impact of combat anxiety on the likelihood of friendly fire accidents where response inhibition may contribute. Chapter 6 explored the effect that acute task-relevant anxiety had on response inhibition performance. Participants' performance on modified SARTs containing anxiety-provoking pictures of spiders as Go or No-Go stimuli was compared to their performance on standard digit-stimuli SARTs. Chapter 7 further examined the impact that anxiety had on response inhibition in order to better understand the findings from Chapter 6 and to resolve debate around different findings. This time, negative and neutral pictures that were either predictive (task-relevant) or non-predictive (task-irrelevant) of imminent No-Go digit stimuli were used. Finally, in Chapter 8, highlights and limitations of each Chapter's experiments are discussed and this body of work as a whole is considered.

2 Friendly fire and the Proportion of Friends to Foes

2.1 Rationale

Action slips, or losses of inhibitory control, could be responsible for some friendly fire incidents. The aim of the experiment within this Chapter was to gauge whether SART-like tasks could be used as models for some friendly fire incidents, despite the traditional SART's artificial appearance. A simulated firearms task was created, incorporating live human actors, infrared emitter guns, and a room-clearing exercise that had similarities with military operations in urban terrain. To explore how different proportions of friends to foes on a battlefield may affect error rates, the proportion of foes to friends that participants encountered was manipulated from a ratio that replicated the high Go, low No-Go proportion of the SART, to lower-Go ratios.

2.2 Abstract[1]

Factors such as poor visibility, lack of situation awareness and bad communication have been shown to contribute to friendly fire incidents. However, research on an individual's ability to inhibit their motor response to shoot when a non-target is presented has appears to have been over-looked. This phenomenon may have been modelled empirically using the SART computer task. The SART is generally a high Go, low No-Go detection task whereby participants respond to numerous neutral or Go stimuli and withhold to rare targets or No-Go stimuli. The current experiment was a pilot study where I aimed to provide an ecologically valid application of the SART to a small arms simulation. This was done to test whether lack of motor response inhibition could be contributing to some friendly fire accidents. Seven university students engaged in a small arms simulation where they used a near-infrared emitter gun to clear an upper floor of a building, by firing at confederates designated as enemies and withholding fire to confederates designated as friends. All participants completed three conditions which were differentiated by the proportion of enemies to friends present. Participants failed to withhold responses more often when the proportion of enemies was higher or closer-replicated the SART, suggesting that a pre-potent motor response routine had developed. This effect appeared to be disproportionately more substantial in the high foe condition relative to the others. Participants also subjectively reported higher levels of on-task focus as foe proportions increased, suggesting that they found the challenge of higher foe proportions more mentally demanding. While only a pilot study, the current experiment provides a solid foundation on which to further explore the application of the SART to battle scenarios. Future research could also closer examine the nature of the performance reductions associated with high proportions of foes, as it appears that this is more complex than a simple linear relationship.

2.3 Introduction

Modern battlefields present many challenges to preventing friendly fire. Battles are more frequently being fought in urban environments, where engagements are typically at close range and engagement times are short, meaning that quick reaction times are crucial (Committee on Defense Intelligence Agency Technology Forecast, 2005; Glenn, 1996). Fire can be received from countless different angles and

[1] Published paper. This chapter is based on the first experiment within the following paper: Wilson, K. M., Head, J., de Joux, N. R., Finkbeiner, K. M., & Helton, W. S. (2015). Friendly fire and the Sustained Attention to Response Task. *Human Factors, 57*, 1219–1234.

directions and it can be difficult to gain concealment (Helmus & Glenn, 2005). Battle lines are often ill-defined and allied soldiers and foes frequently share the same space. Furthermore, hostiles often deliberately co-mingle with civilians in order to confuse opponents, and have been known to use civilians as body shields (Chang, 2007). Other individuals within the battle environment may include security personnel, local police, or members of various non-government organisations such as those providing humanitarian aid (Hollands & Neyedli, 2011).

Operations in urban terrain are often unstructured and unpredictable which can compromise situation awareness (see Endsley, 2000). It can be difficult to know whether rounding a corner will reveal the presence of foes, civilians, or even allies. Technological aids can at times be ineffective or even misleading in urban battle environments. Blue force tracking devices (see Armenis, 2010; Ho et al., 2013), which use GPS technology to visually map the location of friendly forces, often suffer from reliability issues in urban environments. Buildings and other surrounding structures can impede the GPS signal, leading to “deadspots” and lags. Even short delays in the information (e.g., 10 s) can render them ineffective, even when users are aware of the time lag (Bryant & Smith, 2013). Identification friend-or-foe aids, which use laser interrogators and helmet mounted transponders, can be problematic when they are not 100% reliable, which is typically the case (Dzindolet, Pierce, Beck, Dawe, & Anderson, 2001; Kogler, 2003; Parasuraman & Riley, 1997).

Inhibitory control may be a contributing factor in some friendly fire accidents. When soldiers are engaged in intense firefights in complex terrain, such as those common in urban environments, they may be confronted with a large number of enemy combatants, but also on rarer occasions, civilians or comrades. After firing at each hostile target they are confronted with, again and again, soldiers may struggle to inhibit their responses to shoot when a civilian or a comrade appears. The Sustained Attention to Response Task (SART; Robertson et al., 1997) may provide an empirical model of this process.

The SART is a Go/No-Go response task whereby participants respond to numerous Go stimuli while withholding to rare No-Go stimuli (Robertson et al., 1997). The Go stimuli occur 89% of the time, and the No-Go stimuli occur 11% of the time. Performance on the task is measured by errors of commission (failing to withhold to a No-Go stimulus), errors of omission (inappropriately withholding to a Go stimulus), and response time to Go stimuli. The primary measures of interest in the SART are errors of commission. Errors of commission are characteristically high in the SART; an error rate upwards of thirty to fifty percent is not uncommon (Carter et al., 2013; Head & Helton, 2012). This is related to the high Go nature of the task (Stevenson et al., 2011).

The SART, or SART-like tasks, have not been examined in a more realistic firearm simulation using actual moving humans as Go and No-Go stimuli, i.e. foes (Go stimuli) and “friendlies” or civilians (No-Go stimuli). Unlike previous studies with the SART using computers with simple digit or word stimuli, the intent was to see whether the pre-potent motor ballistic routine occurs when participants have to physically shoot at foes (Go stimuli) and withhold from shooting friends (No-Go stimuli).

Whether the SART could provide an empirical model for some battlefield scenarios was investigated. Using a relatively realistic paradigm in order to achieve a good level of ecological validity, participants were instructed to physically search multiple rooms on a floor of a building. Confederates acting as foes or friends were stationed in different rooms. To explore how different proportions of foes and friends affected error rates three conditions were created which varied in the proportion of foe-to-friendly confederates: a target rich, high enemy condition (89% foes); a target sparse, low enemy condition (11% foes); and an even enemy–friendly condition (50% foes).

It was expected that the proportion of enemy to friendly confederates would have a differential effect on error rate. More specifically, it was predicted that a higher amount of foes (Go stimuli) presented would encourage the development of a pre-potent motor response routine which would be difficult for participants to actively inhibit. In other words, conditions with higher proportions of foes relative to friends should have resulted in a higher rate of failures to withhold pulling the trigger to friends, or friendly fire. Additionally, it was predicted that participants would find the conditions more mentally demanding as the proportion of enemies increased, due to the added requirement to actively inhibit responses in this condition. This should be reflected in the questionnaire responses. Also of interest was whether any increase in friendly fire errors as foe proportion rose was linear or non-linear (e.g., an accelerating change). If performance begins to rapidly deteriorate from upwards of a certain foe proportion, this has implications for attempting to identify the proportion concerned, given that an environment with that concentration of foes (and higher) could be particularly dangerous for allies.

2.4 Method

2.4.1 Participants

Eight undergraduate students (five females, three males) from the University of Canterbury participated as a course requirement. They ranged in age from 21 to 46 years, with a mean age of 25.3 years (*SD* = 9.2). According to self-reports, all participants had normal or corrected-to-normal vision and had little to no firearm experience.

Figure 2.1. Steradian SX-7 infrared emitter gun.

2.4.2 Materials

Participants were instructed to clear rooms on a single floor, by firing at foes but avoiding firing at friends. The participants and confederates were armed with a Steradian SX-7 infrared emitter gun (see Figure 2.1.). This was a laser-tag gun weighing 1.3 kg (2.8 lb) and made primarily of machined metal.

Several rooms and hallways on a single floor of a building (see Figure 2.2.) were used. Positioned around this floor were nine confederates acting as stimuli for the tasks. They were not instructed to dress in a particular way and hence wore a variety of casual clothing and had their faces uncovered. These people were stationed within nine separate zones, which were marked out by chalk on the floor's carpet. The zones were each approximately 5 m^2 in area allowing the confederates some freedom of movement and to take a variety of positions.

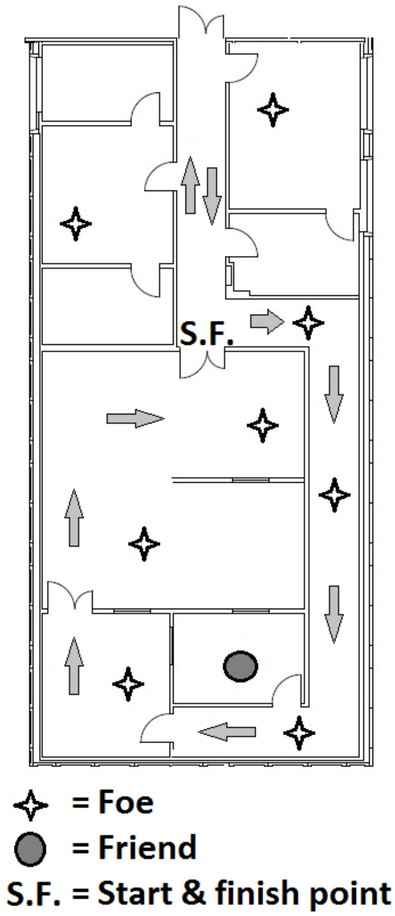

Figure 2.2. Example floor-plan of task area.

There were three conditions: high Go (89% foes); low Go (11% foes and 89% friends) and equal Go No-Go (50% foes). The visual cue signalling whether a confederate was a friend or foe was the presence of a hat upon their head. Foes (Go stimuli) wore hats whereas friends (No-Go stimuli) did not. The hats varied in shape and colour to ensure additional realism of modern asymmetrical conflicts. Also, it simulated the battlefield, where aspects of the uniform indicate which force a soldier is aligned with. The confederates each possessed a personalised list identifying whether they were to have their hat on or off for each individual trial. This list was created quasi-randomly, with the constraints being that over each condition the proportion of Go stimuli to No-Go stimuli had to meet the required amount; there were never fewer than seven Go stimuli for a particular "circuit" in the high Go condition and never fewer than seven No-Go stimuli for a circuit in the low Go condition. For example, in the high Go condition there were 89% Go stimuli and 11% No-Go stimuli. Participants completed four non-stop circuits of the floor without any break in between circuits. Therefore a high Go condition or trial contained 32 Go stimuli and 4 No-Go stimuli. This arrangement was selected instead of a mandatory 8:1 ratio *per circuit* to avoid the possible situation of participants guessing stimuli using a process of elimination. Participants wore a GoPro Hero 2 video camera upon their head to record each task. The footage was later analysed to identify when the participants fired their emitter guns at confederates.

A modified version of the NASA-Task Load Index (TLX) scale (Hart & Staveland, 1988) was used to gauge subjective workload. This version was determined via prior factor analyses (see Bailey & Thompson, 2001; Ramiro, Valdehita, Lourdes, & Moreno, 2010) and consisted of the following four subscales: mental demand, physical demand, temporal demand, and effort. A global workload measure, which was the combined average of the responses to the four subscales, was also of interest. In addition, to measure their "task focus," participants answered three self-report questions: one about concentration (How focused on the task were you?), one about task-related thoughts (How much did you think about the task?) and one about task-unrelated thoughts (How much did you think about something other than the task?). The average of these was calculated to give the "task focus" score. Both the NASA-TLX and the Task Focus questions were rated on a 0–100 scale and completed with paper and pencil at the conclusion of each trial.

Figure 2.3. Example of a participant clearing an area.

2.4.3 Procedure

Participants surrendered their watches and cell phones upon reporting for the study. They were then shown the course and told which direction they were required to move in. They were also shown how to hold and shoot the gun, with their gun to be held in a "low ready" position as they approached each zone on the course. The experimenter prompted the participant when they were to begin each task. Participants were instructed to move swiftly throughout the floor, clearing each zone as they went (see Figure 2.3). The order in which they cleared the nine zones was predetermined and fixed for the experiment. Participants were told to be as quick and accurate as possible when they had encountered a person, firing at foes (Go stimuli) and withholding their fire to friends (No-Go stimuli). Each confederate was instructed to have his/her gun raised and pointed at the participant when the participant entered their zone and to hold for approximately 1 s before firing on a participant. For the purpose of consistency, confederates fired regardless of whether they were acting as a friend or a foe. They were further instructed to try to behave in a manner as consistently as possible across trials (e.g., consistent stance and facial expressions), so that their only differentiating feature between friend and foe roles was a hat clearly visible on their head (foe). Participants received no feedback on their decision after each encounter, for example, a confederate acting as a foe did not behave differently if the participant fired a shot versus failed to fire a shot at them.

Participants each completed one practice circuit. This was used to familiarize them with the task but not used to screen out any participants. Participants completed all three conditions in a within subjects design. For each condition, participants completed four full circuits of the floor without stopping. There was a break of approximately 2 min between each condition. During this interval participants had time to recuperate in case they were physically tired from their efforts in the previous condition. During this break the confederates were free to swap zones with other confederates. Participants completed the workload and task focus scales on three occasions immediately after completing each experimental condition. The order in which participants completed the conditions was counter-balanced to the best degree possible. Because of the low sample size six different orders (three factorial) were used. The order for each of the first six participants was randomly selected from this pool of six orders. For the remaining two participants this process was then repeated. Consequently, two orders were used twice while four orders were used just once. No feedback on participants' performance was given until the end of the experiment. The experiment took approximately 20 min to complete.

2.5 Results

Data was firstly examined for outliers and normality. As a result of this, one participant's results were excluded due to excessively slow movements; thus results were analysed for seven participants. A Grubbs test (Grubbs, 1969) indicated the presence of a further outlier within the data for commission errors for the high foe (target rich) condition, where one participant made many more commission errors than the other participants. Given that the sample size was already very small and that the current investigation was a pilot study, this participant's data was retained. Main effects for condition were tested using one-way repeated-measures ANOVAs. When appropriate these were followed with polynomial trend analyses for linear and quadratic trends as well as planned orthogonal contrasts (see Keppel & Zedeck, 2001) to further investigate the effect of increasing foe proportions on the measures. Assumptions of sphericity were checked with Mauchly's test (Field, 2009).

2.5.1 Behavioural measures

For the three conditions, means, standard deviations, and effect sizes for the main effects are presented in Table 2.1. For errors of commission, Mauchly's test indicated that the assumption of sphericity had been violated; therefore degrees of freedom were adjusted using the Huynh-Feldt correction (Field, 2009). There was a significant main effect for foe proportion on friendly fire errors (errors of commission), $F(1.09, 6.56) = 6.11$, $p = .04$, $\eta_p^2 = .50$. As the proportion of foes increased, the probability of friendly fire errors also increased. Note that as mentioned previously, a Grubbs test detected an outlier within the data for errors of commission and therefore this result should be treated with caution. A linear trend analysis was not significant, $F(1, 6) = 5.6$, $p = .06$, $\eta_p^2 = .48$. There was a significant quadratic trend in the relationship however, $F(1, 6) = 9.2$, $p = .02$, $\eta_p^2 = .61$. A planned orthogonal contrast indicated that the high foe (target rich) condition was significantly different to the medium foe and low foe (target sparse) condition, $F(1, 6) = 6.46$, $p = .04$, $\eta_p^2 = .52$. There were no omission errors made by any participants in any of the tasks. Due to the nature of the task, it was not possible to accurately and reliably measure response time in the fashion that is typical for the SART, which is the time taken for a response to each stimulus at the individual trial level. For a measure of time, the time taken for participants to complete each circuit (circuit completion time) was instead measured, which consisted of nine trials, or nine stimuli presentations, each. There were no significant differences for circuit completion time over conditions, $F(2, 12) = 1.19$, $p > .05$, $\eta_p^2 = .17$. There was, however, a trend apparent, with time appearing to increase in a linear fashion across the conditions from low foe to high foe, although a polynomial contrast was not statistically significant for this linear trend, $F(1, 6) = 2.52$, $p = .16$, $\eta_p^2 = .30$.

Table 2.1. Behavioural measures: Means and standard deviations for each condition and effect sizes for main effects.

	Condition			
Measure	Low Foe (target-sparse)	Even	High Foe (target-rich)	Effect size (η_p^2)
Friendly fire / Errors of commission (%)*	3.6 (4.6)	4.8 (8.7)	23.5 (25.3)[a]	.50
Failure to fire / Errors of omission (%)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	.00
Circuit completion time (seconds)	48.0 (12.3)	49.4 (13.0)	51.1 (15.8)	.17

[a]Denotes significant difference between selected condition and the remaining two conditions (planned orthogonal contrast). *Denotes significance of a main effect at the $p < .05$ level.

2.5.2 Subjective measures

For the three conditions, means, standard deviations, and effect sizes for main effects are presented in Table 2.2. One participant failed to complete over half of the NASA-TLX items and was thus excluded from the subjective data analyses, leaving results from six participants. There were no significant main effects for condition on the global workload measure or any of the NASA-TLX subscale items, $p > .05$. For the task focus measure, there was a significant main effect for foe proportion, $F(2, 10) = 3.98$, $p = .05$, $\eta_p^2 = .44$. There was a significant linear trend in this relationship, $F(1, 5) = 6.3$, $p = .05$, $\eta_p^2 = .56$. A planned orthogonal contrast indicated that the difference between high foe (target rich) and the two other conditions was approaching significance, $F(1, 5) = 6.04$, $p = .06$, $\eta_p^2 = .55$.

Table 2.2. Subjective measures: Means and standard deviations for each condition and effect sizes for main effects.

	Condition			
Measure	Low Foe (target sparse)	Even	High Foe (target rich)	Effect size (η_p^2)
Global workload	63.3 (18.7)	66.8 (15.3)	70.0 (17.5)	.33
Mental demand	56.7 (26.6)	64.2 (25.2)	67.1 (22.9)	.35
Physical demand	69.2 (11.6)	71.7 (10.3)	72.9 (15.7)	.04
Temporal demand	67.5 (28.6)	61.3 (24.4)	66.3 (26.2)	.22
Effort	58.5 (27.6)	66.0 (10.8)	71.5 (14.3)	.32
Task focus*	77.9 (14.3)	80.3 (13.6)	86.3 (10.3)[a]	.44

[a]Denotes significant difference between selected condition and the remaining two conditions (planned orthogonal contrasts). *Denotes significance of a main effect at the $p < .05$ level.

2.6 Discussion

Participants cleared the floor of a building, firing at confederates representing foes and withholding fire to confederates representing friends. All participants completed three conditions which were differentiated by the proportion of foes to friends present. As hypothesized, the probability of friendly fire (failing to withhold a response) increased as the proportion of foes became higher, or the environment became target *richer*. Subjective reports of task focus were also higher as foe proportions increased. While there were no significant differences between the times taken to complete the courses, there was a trend suggesting that participants took longer when foe proportion was higher, perhaps further reflecting that they were finding this condition more challenging. Indeed, although there was no significant main effect for foe proportion on global workload or any of the NASA-TLX subscale items, there was a trend whereby both global and mental workload increased as foe proportion became higher. Furthermore, scores were generally high, indicating participants found their tasks to be demanding.

The finding that a higher proportion of foes (Go stimuli) was associated with a higher percentage of failures-to-withhold is consistent with much literature on the SART (Carter et al., 2013; Head & Helton, 2012; Stevenson et al., 2011). The higher proportion of foes appears to have caused a stronger pre-potent motor response routine to develop, thus making it difficult for participants to withhold fire to the rarely-occurring friends. Interestingly, this effect of probability on incidence of friendly fire appears to be non-linear, as shown by the quadratic relationship observed. Friendly fire errors were at similarly infrequent levels in the low foe and medium foe conditions, however they were markedly higher in the high foe condition. There may exist a threshold, where the foe proportion surpasses a certain level and the pre-potent motor ballistic routine disproportionately increases in strength, causing commission errors to increase markedly. If so, this threshold appears to be somewhere between the 50% and 89% foe/Go proportion, that is, a target-rich environment. This is currently only speculation however, and authors of future research may benefit from more closely examining the functional relationship between friend-foe probability and friendly fire. One challenge to the interpretation that a higher foe proportion led to greater failures to withhold firing relates to the presence of an outlier within this data. Specifically, a Grubbs test indicated that the high amount of friendly fire errors made by one participant in the high foe condition was a statistically significant outlier. This participant's data was retained however due to the sample size already being very low, and because this experiment was intended to be a pilot study. Readers should treat the main effect found here with caution. Following this pilot study a study employing a larger sample size will be employed, making it possible to be more certain about the effects of foe proportion on friendly fire errors.

The observation that one of the seven participants made many more friendly fire errors than others in the high foe condition actually raises another interesting question, that being whether some people are much more prone to response inhibition errors (commission errors) than others. Much literature on the SART suggests that fast responding is often responsible for commission errors (Head & Helton, 2012; Helton, 2009; Peebles & Bothell, 2004). This suggests that the participant who made the large amount of inhibition errors was often faster to fire (the typical SART speed–accuracy trade-off). Note that the time measurement employed in this experiment could not be used to detect whether there was indeed a strong relationship between this participant's speed of responding and inhibition errors.

The finding that the task focus scores were the highest for the high foe condition is in line with previous findings (e.g., Helton et al., 2010) that high Go, low No-Go tasks such as the SART place additional response inhibition demands on individuals which do not occur in perceptually equivalent low Go tasks, for example, the medium-foe and low-foe conditions. The high foe condition—the condition where task focus scores were the highest—also had the highest probability of friendly fire errors. Participants may have experienced heightened task focus as foe proportion increased due to an increased demand on concentration. This result is in line with prior findings that high Go, low No-Go tasks are mentally challenging (Head & Helton, 2012; Stevenson et al., 2011). The self-report results are consistent with the finding that in the high foe condition participants struggled to withhold firing and thus made more friendly fire errors (errors of commission). The participants were aware of the challenge posed by high Go probability. In general, scores for task focus were quite high, suggesting that participants took their assignment seriously.

While there were no significant differences within the makeshift time measure over conditions, there was a slight trend suggesting that as foe proportion increased, participants took longer to complete circuits. The large effect size supports this observation, despite statistical non significance. Perhaps this result is related to the above finding that participants reported more focus as foe proportion increased. The heightened concentration may be associated with a slowing of the physical pace around the course. Alternatively, the fact that this condition required more shooting (more motor movement) may be responsible for this result. It should be noted though that this measurement of time was not conducive to examining whether response times changed at the *individual trial level* over conditions. A more controlled experimental paradigm may enable this.

The limitations of the modified NASA-TLX used here should be noted. Using just four of the subscale items makes direct comparisons with the original NASA-TLX (at a global level) more difficult. As for the four NASA-TLX subscales that were employed here, these were not modified in any manner meaning that direct comparison with these subscales within other research is possible.

Due to the intricate and time-consuming nature of the task (for the researcher), only 8 participants were recruited, and data from only 7 were subsequently included as one participant failed to comply with instructions, resulting in a small sample size. A larger sample may have revealed more results that were statistically significant. This is a plan for future research; however, the need for large numbers of confederates means this kind of research with live human actors is resource challenging. Despite the small sample size in experiment one, effect sizes were relatively large, supporting the interpretation of the reported findings.

The current findings suggest the pre-potent motor response routine may occur in some battlefield scenarios where soldiers are demonstrating SART-like responding, by responding to frequently occurring “Go stimuli” (foes) and only rarely needing to withhold to infrequently occurring “No-Go stimuli” (comrades or non-combatants). However, as it was not possible to measure response times for individual trials, it is unclear whether performance was affected by the speed–accuracy trade-off typically seen in the

SART. Subjects that respond faster usually make more commission errors (failures to withhold) in the SART.

Authors of future research could also look closer at the proportion of enemies relative to friends where friendly fire rates begin to increase markedly. It may be that there is a foe proportion where performance begins to deteriorate rapidly, rather than it doing so in a predictable linear fashion. Indeed the present results show little difference between low foe probability (11%) and moderate foe probability (50%). The real difference in rates of friendly fire were for the target rich, high foe probability condition (89%). Improved knowledge of this functional relationship between friend-foe proportions and the likelihood of friendly fire errors could assist military personnel in both identifying environments which are particularly high-risk for friendly fire incidents and in the future unravelling the cause of the functional relationship itself.

Future research is also needed to see whether people operating firearms in high Go contexts are subject to the same speed–accuracy trade-offs seen in the SART. To examine this, response time (time taken to fire the weapon) needs to be measured at the level of each individual trial, rather than over a set of trials as was done in the current experiment.

These findings may have implications for firearm scenarios. It appears that proportion of friends relative to foes within a battlefield scenario could have an effect on the likelihood of friendly fire incidents; higher concentrations of enemies may lead to more friendly fire accidents. Whether training and technological countermeasures can assist in helping the soldier in this setting remains an open question and demands further research. Some small arms friendly fire incidents may not be due to failures of target recognition per se, but may be due to failures to inhibit a pre-potent action. The findings also suggest the SART may indeed, as Helton and colleagues suggested (Helton & Kemp, 2011) be a useful tool in future research involving accidental shootings.

2.7 Summary

In the current Chapter's experiment, participants completed a simulated firearms task where they confronted live human actors in a room-clearing exercise. The proportion of foes relative to friends was manipulated from low foe (low Go or target-sparse) to high foe (high Go or target-rich). The high foe proportion replicated the proportion of Go stimuli in the SART. Participants had a significantly higher rate of friendly fire errors in the high foe environment. The results of the first experiment suggested the SART may indeed be a useful model for friendly fire incidents. It appeared that the same sorts of errors that are common in the SART may occur in a small arms combat scenario too, when an environment contains a majority of foes intermixed with a small amount of friends or non-combatants. Interestingly, the increase in response inhibition failures as the proportion of Go stimuli (foes) increased was non-linear rather than linear. Later, Chapter 4 examines this closer by using a greater selection of proportions above .5, where inhibition failures appear to become most prolific. The current experiment was promising but perhaps lacked a tight level of adequate experimental control. In Chapter 3 a second simulated firearms task was conducted, wherein tighter experimental control was achieved.

3 Friendly Fire and the Speed–accuracy Trade-off in a High Foe Environment

3.1 Rationale

While the pilot study in Chapter 2 was somewhat applied in nature, at least in terms of typical laboratory-based psychology research, the Chapter 3 study retains much of this ecological validity yet demonstrates more rigorous control and a greater sample size. The experiment reported in this Chapter is essentially a replication of Chapter 2 with the following improvements. Firstly, modification to the infrared emitter guns enabled exact timing of “trigger pull” response times. Consequently relations between response speed and probability of friendly fire could be assessed. Secondly, the power of the experiment to detect effects was increased by increasing the number of trials and the number of subjects. Third, subjects also completed the traditional digit SART on a computer. For both the firearm and computer tasks, subjects completed high Go proportion (89% Go and 11% No Go) and low Go proportion (11% Go and 89% No-Go) versions of the tasks.

3.2 Abstract[2]

Losses of inhibitory control may be partly responsible for some friendly fire incidents. The SART may provide an appropriate empirical model for inhibition failures in some combat scenarios, such as those in cluttered urban environments or close quarters combat, where fast paced engagements are common. In the current investigation, the traditional SART was used in conjunction with a simulated small arms scenario, to test whether the SART and lack of motor response inhibition can be modelled in an ecologically valid environment. Additionally, whether performance was subject to speed–accuracy trade-offs and how error rates were impacted in comparative low Go, high No-Go versions (where Go proportion is reversed) of the task were examined. Thirteen university students completed both a computer and simulated small arms scenario in both a SART (high Go) and low Go condition. Both the computer and small arms scenario revealed similar speed–accuracy trade-offs indicating participants' inability to halt their pre-potent responses to foes (No-Go stimuli) even in a more ecologically valid environment. SART-like tasks may be used in future studies to model friendly fire scenarios.

3.3 Introduction

Reducing friendly fire and collateral damage has never been so crucial, due to the considerable ramifications these accidents have in today's world (Hart, 2004). Technological aids can help soldiers to recognise allies, but have issues which limit their effectiveness. Battles are more and more often being fought in populated urban areas. Blue force tracking devices frequently have delays or lags in positional information due to signal interference from surrounding structures (Bryant & Smith, 2013). Interrogation and response systems (e.g., identify friend or foe transponders) are less effective in urban combat because of the time delay required for the device to interrogate targets (Kogler, 2003); engagements in urban environments are often at very close range and at fast pace (U.S. Department of the Army, 2011). Furthermore, these technologies are unable to positively identify non-combatants or civilians, heightening the risk of collateral damage. Urban operations are often held in target rich environments, where most individuals a soldier confronts are hostile but others are non-combatants or allies. Combined with the rapid pace of engagements, this frequent requirement to fire could cause a soldier to develop a pre-potent firing response, which may be difficult to inhibit when necessary.

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[2] Published paper. This chapter is based on the second experiment within the following paper: Wilson, K. M., Head, J., de Joux, N. R., Finkbeiner, K. M., & Helton, W. S. (2015). Friendly fire and the Sustained Attention to Response Task. *Human Factors, 57*, 1219–1234.

Helton and Kemp (2011) noted that these situations appear to share important characteristics with a computer task frequently used in the psychology laboratory, the Sustained Attention to Response Task (SART; Robertson et al., 1997). This task requires participants to overtly respond to frequently occurring Go stimuli and withhold responses to rarely occurring No-Go stimuli. Typically the Go stimuli are the digits 1 to 9, with 3 being the No-Go stimulus and the remaining digits being the Go stimuli. The high probability of Go stimuli induces the self-organization of a feed-forward ballistic motor routine, which requires significant effort to inhibit when appropriate for the low probability No-Go target stimuli (Helton, 2009; Head & Helton, 2013).

The ubiquitous findings of the SART are negative correlations between errors of commission and response time, indicating a speed–accuracy trade-off (Helton, 2009). The speed–accuracy trade-off of the SART has been attributed to a self-organizing feed-forward ballistic motor response program (Helton et al., 2010). Go stimuli occur in rapid sequences, causing the participants' Go motor response to become pre-potent, which then requires active control to override or inhibit. On the occasions that infrequent No-Go stimuli appear, participants are often physically unable to inhibit the motor response routine in time and thus make an inappropriate response (error of commission; Head & Helton, 2012, 2013; Peebles & Bothell, 2004; Stevenson et al., 2011).

In Chapter 2, whether a modified SART could be used to model friendly fire incidents was investigated by using a small-arms simulation with a higher degree of ecological validity than is seen in much SART research. Results from Chapter 2 suggest that behaviour in some battlefield scenarios can be similar to that typically observed in the SART. Namely, as the required shoot (response) proportion became higher, participants' ability to withhold fire (withhold responses) became poorer. However it was not possible to reliably gauge participants' response times. Furthermore, only a small number of participants were recruited which reduced the power of the experiment to detect statistically significant effects. Therefore in the present experiment, a slightly different paradigm which enabled tighter experimental control was used. A laser gun was modified so that response times could be measured on each individual trial. Measuring response times presented an opportunity to see whether the speed–accuracy trade-off, that is typical of performance in the SART, also occurred when participants operated a firearm. Furthermore, a timing device was used to aid in controlling the movements of confederates (i.e., stimuli presentation). Additionally, the response proportions of the SART were reversed to mimic low Go, high No-Go stimuli tasks more commonly used in the traditional target detection or vigilance literature, the Traditionally Formatted Task (TFT; Helton, 2009). In the TFT the Go stimuli occur 11% of the time, whereas the No-Go stimuli occur 89% of the time, and therefore the TFT was effectively a low-foe, high-friend task in the firearm version. Participants completed both Go proportion conditions (high Go and low Go) using both the small-arms simulation version and the computer task version with digit stimuli. After each of the four tasks participants completed a modified NASA-TLX (Hart & Staveland, 1988) scale designed to assess workload. Finally, a larger number of participants were recruited and each participant completed a greater number of trials.

It was expected that more errors of commission (inappropriately responding to No-Go stimuli) would be made in the high Go versions of both the computer task and firearms task than in their low Go counterparts. Secondly, a speed–accuracy trade-off would be evident in both the small-arms and computer version of the high Go tasks; that is, participants who respond faster to Go stimuli should make more inappropriate responses to the No-Go stimuli. The modified NASA-TLX global workload rating was expected to be higher for the high Go than low Go versions of both the computer-digit and firearms tasks because unlike low Go situations high Go tasks require responses to be inhibited on occasions when rare No-Go stimuli occur.

3.4 Method

3.4.1 Participants

Thirteen undergraduate students (seven males, six females) who were rewarded with a NZD$20 voucher participated in the experiment. They had had normal or corrected-to-normal vision based on self-report and ranged in age between 18 and 45 years (*M* = 26.2, *SD* = 8.6). The participants had little to no firearm experience.

3.4.2 Materials

All subjects completed both a computer-digit and a firearms tasks in both a high Go, low No-Go (Go 89%, No-go 11%) version and in a low Go, high No-Go (Go 11%, No-Go 89%) version. The high Go computer-digit task corresponds to the traditional SART while the low Go tasks are examples of the Traditionally Formatted Task (TFT; see Helton, 2009) vigilance task. There were thus four tasks in total. As with the experiment in Chapter 2, the high Go tasks could be thought of as target-rich scenarios and the low Go tasks as target-sparse scenarios. In the computer tasks, Go stimuli were the equivalent to foes in the firearm task, just as No-Go stimuli were the equivalent to friends. Participants were instructed to respond as quickly and accurately as possible during all tasks. Stimuli presentation and recordings of response times and accuracy were performed by personal computers running E-prime 2.0 software (Schneider, Eschman & Zuccolotto, 2002). A Steradian SX-7 infrared emitter gun was used for recording participant responses in all tasks. In order to measure response time, the SX-7 gun was modified (see Figure 3.1). Attached to the gun’s trigger was a micro switch (unobtrusively within the gun), which was wired to an electrical circuit board from a computer mouse. This enabled the recording of responses using the E-prime software.

Figure 3.1. Modified Steradian SX-7 infrared emitter gun containing added micro switch (see below grip).

Computer tasks. Participants were seated 50 cm in front of a computer (377 mm x 303 mm, 75 Hz refresh rate) mounted at eye level. Participants' head movements were not restrained. The computer SART was nearly an exact replica of that by Robertson et al. (1997) except that instead of pressing a key to respond, participants pulled the trigger on the modified Steradian SX-7 gun so that the physical response was identical between tasks. The gun was not pointed at the screen or anywhere in particular; participants were told to rest it comfortably on their laps (see Figure 3.2). The computer tasks were not characterised to participants in any particular way, such as an operational scenario.

For the computer tasks, participants were instructed to respond to Go stimuli and withhold to No-Go stimuli. In the high Go situation (SART) participants were instructed to respond to all digits except "3" while in the low Go situation (TFT) the task was to respond to the "3" and ignore the remaining digits. Both tasks were 4.3 min in duration and consisted of 225 trials. Digits were displayed in Arial font and varied randomly in size (48, 72, 94, 100, or 120 point), displaying between 12 and 29 mm in height.

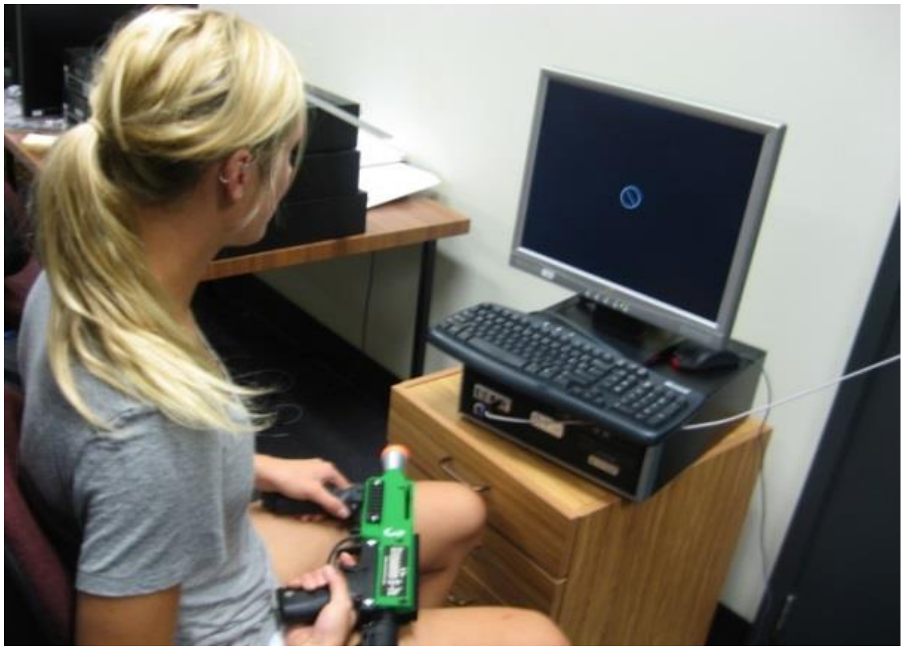

Figure 3.2. Example of the computer task setup.

Firearm tasks. The firearm tasks involved the participant being stationed in a hallway, standing or leaning at a “leaner” structure 1,240 mm high (Figure 3.3). The leaner had a flat top on which a pillow was placed which gave a similar feel to a sandbag and helped participants to remain comfortable. At the end of the hallway there was a small 0.5-m-wide doorway a distance of 5.8 m from the participant. Stationed here was a confederate, also carrying an SX-7 gun and wearing a black balaclava (with small holes for the eyes and mouth), a black baseball cap, and a black shirt. An opaque black cloth was put up in the doorway, obscuring the entire section from the floor to a height of 1.2 m up the doorway. This was to ensure that the foot movement of the confederate did not appear first during trials. Participants wore earmuffs so that they could not hear any of the movements of the confederate which could have provided them with a cue for stimulus onset. For consistency purposes participants also wore the earmuffs in the computer tasks. The black balaclava was worn so that participants were not distracted by visual cues from facial expressions. This also forced participants to concentrate on the cap direction which was the primary cue for friend or foe stimuli: forward-facing signified a member of the same force, backwards-facing signified a member of the opposing force. Adjacent to the doorway and on the side not visible to the participant was a research assistant who monitored visual cues on a computer detailing which way the cap was to face for each subsequent trial. In between doorway appearances, when the balaclava-clad confederate was out of view of the participant, the research assistant, who was also out of view of the participant quickly turned the cap around when required.

There were 180 trials for each of the firearm tasks. Due to the physically demanding nature of the tasks (with a real person moving), trials took 4 s each. The total time for each task was 12 min. As with the comparative computer tasks, in the high Go task the probability of friend was .11 (No-Go stimulus) to appear, and the probability of foe .89 (Go stimulus). These probabilities were reversed in the low Go situation.

Figure 3.3 Example of the firearm task setup, looking over the shoulder of a participant.

Questionnaire. A paper-and-pencil version of the NASA-TLX (Hart & Staveland, 1988) was used to subjectively assess workload. This was the same as the version used in Chapter 2. It contained four of the NASA-TLX subscales: mental demand, physical demand, temporal demand and effort. A global workload measure, which was simply the average of the four subscales, was also of interest.

3.4.3 Procedure

All participants were tested individually. Before each task participants were given a short practice (18 trials) to familiarize them with the task. This was not used to remove any participants based on performance. Participants completed all four tasks (computer-digit low Go, computer-digit high Go, firearm low Go, firearm high Go). The order of the tasks was counterbalanced in a nested design: approximately half of participants (seven) did the firearm tasks first, and the remainder (six) did the computer tasks first. Within these, approximately half completed a low Go situation first. Following each of the four tasks participants immediately filled out the questionnaire. No feedback was given to participants on their performance until the end of the experiment. The whole experiment took approximately 45 minutes to complete.

Computer tasks. Each trial a single digit, selected by random from the digits 1–9 (inclusive) was visually presented on the computer screen for 250 ms (see Figure 3.4). This was followed by a 900 ms mask, which was a ring (29 mm in diameter) with a diagonal cross in the middle spanning from one side to the other.

Figure 3.4. Task schematic for computer digit task depicting an example of three consecutive trials.

Firearm tasks. Participants were instructed that they would be trying to shoot a person (confederate) appearing intermittently in a doorway. Some of the time the person would be a friend, that is someone in their team, and other times the person would be an enemy, from an opposing force. This was to be signalled by the direction of the cap which the confederate was wearing. The confederate was also armed with an SX-7 gun, and participants were told this person would be aiming at them too regardless of which way the cap was facing. This was to give participants more incentive to act quickly and accurately. Participants were informed that their precise point of aim was not overly important here; if they pulled the trigger, they effectively shot the target. A new trial began every 4 sec. Subjects were told a balaclava-clad confederate would be visible in the doorway for approximately 1.5 s (see Figure 3.5). The onset of a 1.5 s burst of white noise (75 dBA) audible to the confederate via earphones signalled that the confederate was to step into the doorway and step out of the doorway when the noise ceased. The confederate was careful to move out in the same manner on each trial regardless of whether they were fulfilling a friend or foe role. Only one step was necessary to make the transition from beside the doorway into a visible position inside the doorway. Response times in the firearm tasks were measured from the onset of the white noise and would therefore have a slight lag due to the confederate’s need to move into view. The confederate behaved in the same manner following a participant’s shot or no-shot regardless of whether the confederate was acting as a friend or foe.

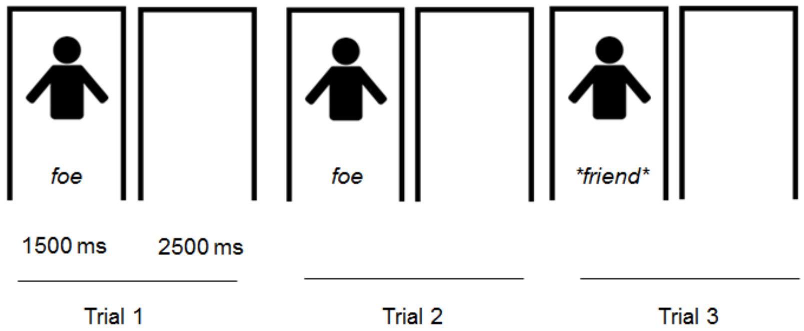

Figure 3.5. Task schematic for firearm task depicting an example of three trials.

3.5 Results

3.5.1 Behavioural measures

The means and standard deviations for each condition are presented in Table 3.1. To explore the differences between conditions 2 (apparatus: computer vs. firearm) x 2 (Go proportion: high Go vs. low Go) repeated measures ANOVAs were used. For friendly fire errors or errors of commission, there was a significant main effect of Go proportion, $F(1, 12) = 170.18$, $p < .001$, $\eta_p^2 = .934$. There was also a significant main effect of apparatus, $F(1, 12) = 9.62$, $p = .009$, $\eta_p^2 = .445$. Furthermore, there was a significant interaction effect for apparatus with Go proportion, $F(1, 12) = 11.71$, $p = .005$, $\eta_p^2 = .494$. Commission errors were higher in the high Go proportion than the low Go proportion and higher in the computer tasks than the firearm tasks. The magnitude of the difference between the two Go proportions was larger in the computer tasks than the firearm tasks. For failures to fire or errors of omission, there was a significant main effect for apparatus, $F(1, 12) = 10.71$, $p = .008$, $\eta_p^2 = .459$. More omission errors were made in the firearm tasks than the computer tasks. There was no significant main effect for Go proportion, $F(1, 12) = .723$, $p = .412$, $\eta_p^2 = .057$, nor was there a significant interaction effect between apparatus and Go proportion, $F(1, 12) = 3.84$, $p = .074$, $\eta_p^2 = .242$. For response time, there was a significant main effect for apparatus, $F(1, 12) = 2643.00$, $p < .001$, $\eta_p^2 = .995$, and for Go proportion, $F(1, 12) = 75.34$, $p < .001$, $\eta_p^2 = .863$. There was also a significant interaction between apparatus and Go proportion, $F(1, 12) = 11.87$, $p = .005$, $\eta_p^2 = .497$. Response times were faster in the high Go proportion than the low Go proportion and faster in the computer tasks than the firearm tasks. The magnitude of the difference between the two Go proportions was larger in the computer tasks than the firearm tasks. Pairwise comparisons were then performed to further investigate the differences between the high Go and the low Go proportions. The results of these, specifically the effect sizes (unstandardised mean differences) with 95% confidence intervals, are displayed in Table 3.1 (see Cumming, 2014).

Table 3.1. Behavioural metrics: means and standard deviations for each condition, mean differences, and 95% confidence intervals.

Measure	High Go (target-rich)	Low Go (target-sparse)	Mean difference	Lower 95% C.I.	Upper 95% C.I.
Firearm					
Friendly fire/Commission errors (%)	32.7 (16.8)	1.2 (2.2)	31.5	21.3	41. 7
Failure to fire/Omission errors (%)	0.6 (.8)	1.2 (1.1)	-.6	-1.5	.3
Response time (ms)	1111 (63.0)	1248 (63.6)	-137.1	-101.2	-173.1
Computer					
Friendly fire/Commission errors (%)	55.4 (17.7)	0.3 (1.1)	55.1	44.4	65.7
Failure to fire/Omission error (%)	0.4 (.5)	0.2 (.3)	.2	-.1	.5
Response time (ms)	324 (50.9)	398 (32.8)	-72.9	-103.3	-42.6

Note. C.I. = confidence interval.

3.5.2 Subjective measures

The means and standard deviations for each condition are presented in Table 3.2. Like the behavioural results, 2 (apparatus: computer vs. firearm) x 2 (Go proportion: high Go vs. low Go) repeated measures ANOVAs were used to detect any differences between conditions. For the global workload measure, there was a significant main effect for Go proportion, $F(1, 12) = 14.70$, p .002, $\eta_p^2 = .551$. There was no significant main effect for apparatus, $F(1, 12) = 1.97$, $p = .185$, $\eta_p^2 = .141$, however there was a significant interaction between apparatus and Go proportion, $F(1, 12) = 6.33$, $p = .027$, $\eta_p^2 = .345$. Global workload was higher in the high Go proportion than the low Go proportion, and the difference between the two proportions was more pronounced in the computer tasks than in the firearm tasks. Individual subscale items were then analysed. Mental demand was significantly higher for high Go than low Go, $F(1, 12) = 7.74$, $p = .017$, $\eta_p^2 = .127$. Physical demand was significantly higher for high Go than low Go, $F(1, 12) = 5.13$, $p = .043$, $\eta_p^2 = .299$, and also higher for the firearm tasks than the computer tasks, $F(1, 12) = 13.25$, $p = .003$, $\eta_p^2 = .525$. Temporal demand was significantly higher for high Go than low Go, $F(1, 12) = 6.35$, $p = .027$, $\eta_p^2 = .346$. Finally, effort was significantly higher for high Go than low Go, $F(1, 12) = 10.32$, $p = .007$, $\eta_p^2 = .462$. There were no other significant main effects or any interactions for these 4 subscale items, $p > .05$. Pairwise comparisons were then performed to further investigate the differences between the high Go and the low Go proportions. The results of these, specifically the effect sizes (unstandardised mean differences) with 95% confidence intervals, are displayed in Table 3.2 (see Cumming, 2014).

Table 3.2. Subjective metrics: Means and standard deviations for each condition, mean differences, and 95% confidence intervals.

Measure	High Go (target-rich)	Low Go (target-sparse)	Mean difference	Lower 95% C.I.	Upper 95% C.I.
Firearm					
Global workload	60.3 (22.5)	54.9 (21.8)	5.4	0.84	9.9
Mental demand	71.2 (24.3)	65.0 (28.2)	6.2	-2.5	14.8
Physical demand	53.1 (32.4)	45.0 (28.1)	8.1	2.1	14.1
Temporal demand	39.2 (24.2)	40.0 (24.7)	-0.8	-11.4	13.0
Effort	77.7 (22.6)	69.6 (25.0)	8.1	0.9	15.2
Computer					
Global workload	58.4 (17.8)	42.0 (23.3)	16.3	6.3	26.4
Mental demand	70.8 (20.7)	49.6 (32.0)	21.2	3.8	38.5
Physical demand	23.9 (26.1)	22.7 (25.5)	1.2	-4.9	7.2
Temporal demand	60.4 (30.4)	41.5 (27.6)	18.8	5.4	32.3
Effort	78.5 (16.1)	54.2 (33.5)	24.2	4.5	43.9

Note. C.I. = confidence interval.

3.5.3 Relationship between response time and commission errors

Correlations between response times and errors of friendly fire/commission were analysed using standardised z scores for each participant. Significant relationships between response time and friendly fire or commission errors were apparent for both the firearm task and the computer task. Participants with faster response times tended to make more friendly fire errors or commission errors (Figure 3.6.), for both the computer task, $r(11) = -.78$, $p < .05$, and the firearm task, $r(11) = -.64$, $p < .05$.

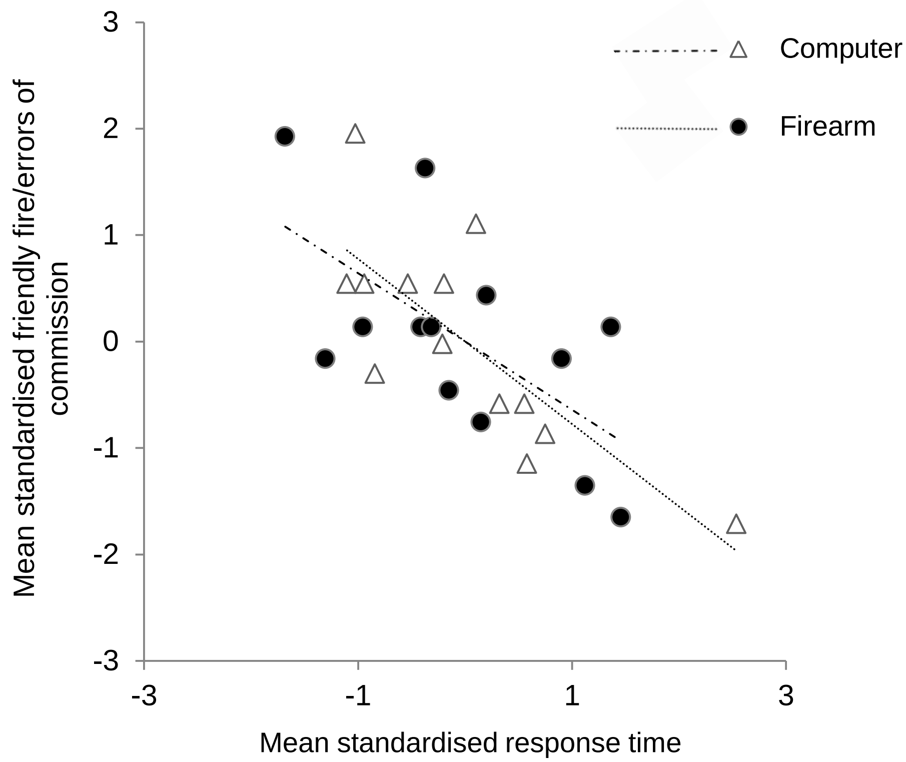

Figure 3.6. Correlations between friendly fire/errors of commission and response time for both the firearm task and the computer task using *z* score transformations.

3.6 Discussion

In the current investigation participants completed both a computer and a simulated small-arms scenario, in both high Go (SART; target rich) and low Go (TFT; target sparse) proportion situations. Participants made significantly more friendly fire errors or commission errors when the Go (foe) proportion was higher. There was strong evidence of speed–accuracy trade-offs, with those participants responding faster in the high Go situations (both firearm and computer) also tending to commit more friendly fire errors or errors of commission. Errors of omission (failure to fire errors) were significantly higher in the firearm tasks than the computer tasks. The global workload ratings were higher for the high Go situations than the low Go situations in both the computer and firearm tasks. This was also the case for all four subscale items: mental demand, physical demand, temporal demand and effort were all significantly higher in the target rich high Go situation than the target sparse low Go situation.

The finding that a higher proportion of foes (Go stimuli) was associated with a higher percentage of failures-to-withhold is consistent with much literature on the SART (Carter et al., 2013; Head & Helton, 2012; Stevenson et al., 2011). The greater amount of firing appears to have caused a pre-potent motor response routine to develop, thus making it difficult for participants to withhold fire to the rarely-occurring friends.

The shorter response times seen in the target-rich high Go proportions as opposed to the target-sparse low Go proportions are further evidence for the development of a pre-potent motor response. Whereas measures of time for the high-foe proportions in the Chapter 2 experiment appeared to actually be longer, in the current experiment the opposite was observed. This is in line with much literature on the SART which shows that high Go, low No-Go tasks cause participants to shorten their response times (Helton, Lopez, & Tamminga, 2008; Robertson et al., 1997). The difference between the Chapter 2 and 3 findings is likely due to participants in the Chapter 2 experiment being able to "self-pace" their movements around the course, whereas in the current experiment the task was externally-paced.

Although speed–accuracy trade-offs were substantial in both the firearm and computer tasks of the high Go proportion, the relationship between response time and commission errors was slightly weaker in the firearm task. This was presumably due to either less accuracy in measuring response time (as the movement of the confederate could not be kept exactly the same across trials), the slower event rate of the task (necessary to be physically possible), or both. The speed–accuracy trade-offs observed are in line with a substantial body of research on the SART (Head & Helton, 2012; Helton, Kern, & Walker, 2009a; Ishimatsu et al., 2016; Peebles & Bothell, 2004; Wilson, Russell, & Helton, 2015b).

The finding that errors of omission or failures to fire at foes were made more often in the firearm tasks than the computer tasks may suggest participants were engaging in momentary rest breaks, for example, "taking breathers." This account for omission errors proposes that when cognitive demands become high participants may compensate by adopting a more conservative response strategy, and thus respond less (Dillard et al., 2014; Doneva & De Fockert, 2013; Helton, Head, & Russell, 2011b). That the differences observed in omission errors here were between the firearm and computer tasks, suggests task physicality could have contributed to this. Perhaps the physical demands of the firearm task coupled with the cognitive demands led to excessive central resource burdens that encouraged participants to take these rest stops.

The findings that the global workload measure and all four of its subscale items were higher in the high Go proportion are in line with the perspective of Helton and colleagues (2010) that the SART places additional response inhibition demands on individuals which do not occur in perceptually equivalent low Go tasks, for example target sparse scenarios. The self-report results are consistent with the finding that in the high Go proportions participants struggled to withhold responding and thus made more mistakes. The participants were aware of the challenge posed by high Go probability. In general, global workload scores were quite high, suggesting that participants took their assignment seriously.

In the current experiment, using a larger number of participants was associated with more results that reached statistical significance, relative to the experiment in Chapter 2. As discussed earlier, the small sample size in Chapter 2 may have led to some of the results being understated (i.e., failing to reach statistical significance). Indeed, effect sizes were similarly large in the current experiment and the improved sample size coincided with more significant results. Nevertheless, the sample size here (N = 13) was still quite small, reflecting one of the challenges of conducting research that is more applied in nature. This type of research is often resource challenging.

As mentioned in Chapter 2, the limitations of the NASA-TLX should be noted here. Firstly, by using just four of the subscale items, making direct comparisons with the original NASA-TLX (at a global level) may be more difficult. For these reasons the global workload measures reported here should be treated with caution. As for the four NASA-TLX subscales that were employed here, these were not modified in any manner meaning that direct comparison with these subscales within other research is possible.

The current findings are consistent with findings often observed with high Go, low No-Go tasks such as the SART, showing that the classic speed–accuracy trade-off occurs in a simulated firearm simulation as well. Whether this is the case in more realistic scenarios remains to be seen. The participants in the present experiment were not trained soldiers and the tasks were still far from a battlefield in terms of consequences. For instance, conditions were not manipulated so that participants might experience the intense emotional components associated with the horrors of war. Participants were not sleep deprived. Furthermore, there were no risks to participants comparable to being seriously injured or killed. However the tasks were undeniably more realistic than a computer task with numbers, and the findings suggest further research also involving manipulations of the aforementioned factors should be conducted. It is actually possible that the effects observed here are understated. Other research seems to suggest that the more “real” a simulated battlefield becomes, the more likely participants are to commit friendly fire errors. Patton (2014) used an immersive virtual environment and a ThreatFire™ belt which administered a shock to participants to simulate hostile return fire (see also Patton, Loukota, & Avery, 2013). Those in the more “life-like” shock condition shot significantly more friends than those in the comparative no-shock conditions. Authors of another study observed that higher levels of arousal were associated with higher rates of friendly fire errors (Famewo, Zobarich, & Bruyn Martin, 2008).

Further research is needed to clarify whether there are differences in the nature of performance between professional soldiers and the unskilled civilians used here. One possibility is that skilled soldiers may actually be even more susceptible to failures to withhold, due to quicker response times resulting from more practice. Indeed, Head and Helton (2014) found that participants made more errors of commission after several weeks of practice on a modified SART. Certainly, another question is how target identification training influences motor inhibition.

These findings have implications for firearm scenarios. It appears that the pre-potent motor response is difficult to inhibit in a high Go, low No-Go situation (e.g., a target-rich environment). Whether training and technological countermeasures can assist in helping the soldier in this setting remains an open question and requires further research. Some small arms friendly fire incidents may not be due to failures of target recognition per se, but may be due to failures to inhibit a pre-potent motor action. Even when in environments where it is normally easy to visually differentiate friend from foe, when fast responses are demanded by the situation, the individual may still fire on friends or civilians. The findings also suggest the SART may indeed, as Helton and colleagues suggested (Helton & Kemp, 2011; Helton et al., 2010) be a useful tool in future research involving accidental shootings. This could perhaps also include law enforcement accidents.

3.7 Summary

In Chapter 3 simulated firearms tasks similar to the tasks in Chapter 2 were conducted. This time though, a greater number of participants were tested, stimuli presentation timings were controlled, and participants' response times were measured.

Participants made significantly more errors of commission or friendly fire when proportions of Go stimuli or foes was higher. They also responded significantly faster in these conditions. The findings suggest the same speed–accuracy trade-off that occurs in the computer-based SARTs may occur in a considerably more applied context such as a battlefield. The self-reports that workload was significantly higher in the high Go (high foe or target rich) versions than the low Go (low foe or target sparse) versions suggest that participants found the high Go nature to be more demanding and required more effort.

Considering Chapters 2 and 3 together, these studies demonstrate that despite the SART's sterile and artificial appearance, this task is a means to examine behaviour in a real-world operational context. As Helton and Kemp (2011) suggested, the SART can be useful for studying and ultimately mitigating action slips, or impulsive real-world behaviours. To my knowledge, this research is the first of its kind to investigate how failures of response inhibition in the SART are associated with friendly fire. Battles are more and more commonly being fought in urban environments, where each force's battle lines are inevitably more loosely defined and non-combatants are also often intermixed within the environment. This research suggests that when the proportion of foes relative to friends and non-combatants is high, soldiers may struggle to inhibit a pre-potent shooting response that has developed through frequent firing. This information could be highly useful for a military commander wishing to identify environments where there is a high risk of friendly fire incidents. For example, if it is known beforehand that soldiers will likely confront a small number of non-combatants at unpredictable moments during an operation, a commander could modify plans accordingly.

Nevertheless, the quandary of how to prevent errors of response inhibition altogether remains. As prior research with the SART suggests, anything that lengthens the time it takes to make responses is likely to help prevent commission errors. Examples of this include altering the instructions given to participants so as to emphasize accuracy more than speed (Seli et al., 2012) and requiring participants to respond in time with a delayed audible cue following stimulus presentation (Seli et al., 2013). Unfortunately, delaying how fast a soldier can fire a shot has obvious shortcomings. While this may reduce the chances of friendly fire accidents, by giving soldiers additional time with which to inhibit a pre-potent motor response, it may make them more vulnerable to being shot by a faster-firing enemy. For this reason, delaying a shooter's speed of firing may not be a good idea for small arms combat, at least not for dismounted soldiers who are confronting enemy soldiers in extremely fast-paced situations (e.g., typical urban operations). To circumvent the seemingly inevitable speed trade-off that an improved ability to withhold responses would normally entail a different approach is required. Chapter 7 addresses one such approach, wherein the effects of providing warning cues that predict the imminent onset of No-Go stimuli are explored.

In many circumstances though, a small cost of speed in return for improved response inhibition will be acceptable. In modern warfare, the use of weapons systems which are operated remotely (e.g., automated turret guns and unmanned aerial vehicles) may be one case where trade-offs in speed are worth the reduced likelihood of friendly fire errors. The consequence of a response that is too slow may or may not lead to a damaged machine after receiving enemy fire (materiel cost), whereas the consequence of a friendly fire error will almost certainly lead to the injury or death of an ally or civilian. In terms of other applied contexts, in many real-world situations it will be advantageous to slow behaviours down to reduce the likelihood of action slips. For example, action slips in nuclear control rooms or manufacturing plants can potentially be catastrophic. Within Chapter 5, one method for improving response inhibition and thus reducing commission errors is explored using a modified SART in which participant’s physical responses were delayed.

Although the experiments used in Chapters 2 and 3 had a reasonable level of ecological validity, there were still aspects which failed to capture the essence of actual warfare. One obvious omission is that participants did not experience acute stress or anxiety, which is common in combat (Helmus & Glen, 2005; Moore et al., 2012). In general, anxiety has a large impact on cognition and overall functioning (Eysenck, Derakshan, Santos, & Calvo, 2007). However its impact on response inhibition and performance in SART-like tasks is not currently clear, due in-part to a lack of relevant research but also to differing findings that have yet to be reconciled. Examining the impact of anxiety on SART-like performance should provide insight as to the impact that acute combat stress might have on the likelihood of friendly fire, at least in environments where response inhibition is important (e.g., target rich environments). Chapters 6 and 7 investigate whether anxiety increases or reduces the likelihood of response inhibition failures.

While Chapters 2 and 3 demonstrate the SART’s potential usefulness in addressing friendly fire incidents on a battlefield, they do not address the underlying cause of why response inhibition failures occur when the proportion of foes in an environment are high. Chapters 4–7 examine this more closely by adopting an exclusively basic or traditional laboratory approach.

4 Go Proportion Influences Performance in SART-like tasks

4.1 Rationale

Chapters 2 and 3 showed that simply changing the proportion of Go to No-Go stimuli had a substantial effect on performance as well as subjective workload. In the Chapter 2 experiment, while the Go proportion increased linearly over the conditions, the increase in the commission error rate was non-linear. Differences were much more prominent between the high go (89% foe) and the even (50% foe) tasks than the differences between the even and the low go (11% foe) tasks. It was possible that a threshold existed, which may have been the Go proportion at which the pre-potent motor response intensified, thus making it much more difficult to withhold responding to No-Go stimuli. This was mainly speculation however, given that firstly, response times were not measured in the Chapter 2 experiment, and secondly, that only three different Go (foe) proportions were used. Chapter 4 further investigates the functional relationship between response proportion and errors of commission, which may have implications for a battle commander who is weighing up the risks of friendly fire.

The experiment in Chapter 4 also includes a thought measure questionnaire, to help understand the underlying cause of performance changes in SART-like tasks. Only minimal differences were observed between self-reported subjective measures over differing foe proportions in Chapter 2. This may have been related to the slightly haphazard nature of the experimental task, which is often inevitable with research that is more applied in nature. The computer-based nature of the current Chapter's experiment should be better-equipped to reveal differences in thought measures over Go proportions, if they do indeed exist. This also presented an opportunity to test the two competing perspectives of SART performance, perceptual decoupling versus response strategy or response inhibition, against each other.

Chapters 2 and 3 used a somewhat applied approach to investigate whether response inhibition errors could be occurring in a friendly fire context. Chapters 4 and onwards use a more basic approach however, in order to examine the underlying causes of friendly fire or response inhibition errors in SART-like situations. Adopting a more traditional laboratory approach enables more rigorous experimental control and better isolation of microcognitive constructs, such as response inhibition and response time or response latency.

4.2 Abstract[3]

The Sustained Attention to Response Task's (SART) usefulness as a measure of sustained attention has been questioned. The SART may instead be a better measure of other psychological processes and could prove useful in understanding some real world behaviours. Thirty participants completed four Go/No-Go response tasks much like the SART, with Go stimuli proportions of .50, .65, .80 and .95. As Go proportion increased, response times decreased while both commission errors and self-reported task-related thoughts increased. Performance was associated with task-related thoughts but not task-unrelated thoughts. Instead of faster response times and increased commission errors being due to absentmindedness or perceptual decoupling from the task, the results suggested participants made use of two competing response strategies, in line with a response strategy or response inhibition perspective of SART performance. Interestingly, commission errors and response times changed in a non-linear manner, despite the linear Go proportion increase. A threshold may exist where the pre-potent motor response becomes more pronounced, leading to the disproportionate increase in response speed and commission errors. This research has implications for researchers looking to employ SART-like tasks and for more applied contexts where the consequences of response inhibition failures can be serious.

4.3 Introduction

While the Sustained Attention to Response Task (SART; Robertson et al., 1997) was initially developed as a tool for measuring sustained attention, it may prove more useful in understanding real world behaviour. Wilson, Finkbeiner, de Joux, Head, and Helton (2014) conducted a simulated firearms task utilising a Go/No-Go response paradigm. Participants confronted a mixture of foes (Go stimuli) and friends (No-Go stimuli) in a simulation of a military or law-enforcement scenario using human actors. They used proportions of high Go (.89), low Go (.11), and medium Go (.50). They found that participants failed to withhold responses (committed errors of commission or friendly fire) more often as the Go (foe) proportion increased. Interestingly, despite the Go proportion increase being linear, the increase in errors of commission was accelerating (not constant linear). There was no detectable difference in commission errors between low Go and medium Go proportions, however there was a large difference between the medium Go and high Go proportions. They were unable to measure response speed though so it was not

[3] Submitted paper. This chapter is based on: Wilson, K. M., de Joux, N. R., Finkbeiner, K. M., Russell, P. N., & Helton, W. S. (submitted, October 2015). Go-stimuli proportion influences response strategy in a Sustained Attention to Response Task.

clear what relationship this had with Go stimuli proportions. They speculated that a threshold may exist, wherein a pre-potent motor response (see Head & Helton, 2014; Helton, 2009; Helton et al., 2010; Robertson et al., 1997) takes precedence after the proportion of Go responses exceeds equal probability (.50). If such a threshold exists, it would be highly useful to be able to use response proportion to predict when a pre-potent motor response may take effect and seriously impair individuals' ability to inhibit subsequent responses when required. In the context of friendly fire for instance, a law enforcement or military commander may be able to use knowledge of a combat zone to help predict when friendly fire accidents are at a particularly high risk of occurring.

Typically, simple digit stimuli (e.g., 1-9) have been used in the SART. Participants are tasked with responding to Go stimuli occurring 89% of the time (digits 1-9, except for 3), and to withhold responses to rarely occurring No-Go stimuli (the digit 3). Performance is measured primarily by errors of commission (inappropriately responding to a No-Go stimulus), errors of omission (failing to respond to a Go stimulus) and response time to Go stimuli. Errors of commission normally occur much more frequently (30-50%) than errors of omission (5-10%) in the SART (Carter et al., 2013; Head & Helton 2012). Further, performance is typically characterised by a speed–accuracy trade-off: people who respond faster to Go stimuli also inappropriately respond more often to No-Go stimuli (Helton, 2009; Helton et al., 2005; Ishimatsu et al., 2016).

There is ongoing debate regarding the mechanism responsible for errors of commission in the SART. Investigating this will provide insight as to the underlying causes of response inhibition errors that may be occurring in a battlefield environment. One perspective is that commission errors occur because of the monotonous nature of SART stimuli and the task itself. The task induces feelings of boredom and mind wandering (Smallwood & Schooler, 2006) or a state of mindlessness (Manly et al., 1999; Robertson et al., 1997) which in turn results in perceptual decoupling (failures to recognize the No-Go stimuli) and an automatic pattern of responding that requires little effort but is responsible for more commission errors. From the mind wandering perspective, this is said to be evidenced by an increase in task-unrelated thoughts. Proponents of the perceptual decoupling interpretation do recognise that the speed–accuracy trade-off is a major feature of the SART, however they attribute this to the supposed decoupling of conscious perception from the task, which induces faster responding to the Go stimuli and the inability to withhold responses to the No-Go stimuli (Manly et al., 1999; Robertson et al., 1997; Smallwood et al., 2004).

A competing explanation is that the trade-off between speed of response to Go stimuli and the risk of responding to No-Go stimuli is the result of a deliberate response strategy and not decreased external awareness of the identity of stimuli per se (Peebles & Bothell 2004). While SART instructions typically place equal emphasis on accuracy and response speed, participants may favour a strategy that maximises speed over accuracy. Indeed, they may switch back and forth between these strategies dynamically (Head & Helton 2014). With 89% ‘Go’ trials and only 11% ‘No-Go’ trials, the benefit of speed on 89% of trials may outweigh the costs to speed of slowing sufficiently on all trials to avoid inappropriate response to No-Go stimuli (commission error) on only 11% of trials. Peebles and Bothell (2004) show that an Adaptive Control of Thought-Rational (ACT-R; Anderson & Lebiere, 1998) model that incorporates two competing response strategies is able to successfully predict observed relationships between SART response times to Go stimuli and probability of commission errors. The two strategies in their model of SART performance are labelled “encode and click” (respond) and “encode and check.” In the encode and click strategy the participant does not wait to analyse the contents of the stimuli but simply responds to the presence of any stimulus as quickly as possible. This strategy maximizes speed (participants are instructed to respond quickly), which 89% of the time is an effective strategy in the SART. Conversely, the encode and check strategy slows the response to all stimuli because it requires subjects to verify the identity (or at least response category) on all trials. This strategy results in slower responses on all trials, but facilitates the appropriate withholding of a response to No-Go stimuli. The strategy choice is dynamic, in that subjects may switch between the two depending on which they perceive to be the most useful at the time. Rather than adopting one strategy throughout, they revise the perceived strength of each strategy after each success or failure and make adjustments accordingly. For example, after a commission error the perceived usefulness of “check” is enhanced, and after a fast correct Go response, “click’s” usefulness is boosted. This supports the idea that subjects are perceptually aware of the task, as opposed to decoupled during the task. The strategy choice is likely influenced by factors such as top-down control. Prior research has found, for example, that simply altering the task instructions to emphasise either speed or accuracy has a marked effect on task performance, indicating the role of top-down control or strategy choice (Seli et al., 2012).

In addition to top-down strategy choice, task characteristics will affect the strategy adopted. For example, reformatting the task in a way that artificially slows down responses reduces errors of commission in SART-like tasks, as subjects are no longer penalized for performing the more accurate but slower encode and check strategy, because the response itself is designed to take more time (Head & Helton, 2013). For instance, Head and Helton (2013, 2014) altered the response method so that participants were required to move a mouse pointer towards stimuli before then having the opportunity to click to respond. The additional time that this extra physical movement required, versus simply pressing a button to respond, artificially increased response times and as a result participants made fewer commission errors (see also Seli et al., 2013).

Another task characteristic likely to influence strategy choice would be the relative proportion of Go stimuli to No-Go stimuli. The encode and click strategy (emphasizing response speed) should be biased to occur when there are higher Go proportions, as a high-speed response strategy is maximally beneficial when Go stimuli are more prevalent. This should also result in overall faster response rates in the task with higher relative proportions of Go stimuli, or "Go proportions." The encode and check strategy (emphasizing accuracy) should, however, be biased to occur when there are relatively more No-Go stimuli, as the alternative strategy emphasizing speed would result in more errors in this setting. This would result in a switch toward the slower encode and check strategy and this would result in slower response rates to the Go stimuli.

In the current experiment the aim was to further explore how relative Go/No-Go stimuli proportion affects performance in SART-like tasks. To do this, a number of different proportions were used in a computer-based Go/No-Go task. Following suggestions that the Go proportion's most influential effects on response inhibition occur somewhere upwards of the 50% Go proportion (Wilson et al., 2014), four conditions beginning at 50% Go and increasing in equal intervals through to 95% Go were used. Participants completed all four tasks in a repeated measures design. For each condition the performance metrics of commission errors (failures to withhold to No-Go stimuli), omission errors (failures to respond to Go stimuli) and response times to Go stimuli were recorded along with a questionnaire to measure participants' task-related and task-unrelated thoughts.

As the Go proportion increases from .50 to .95, participants should increase their preference for the strategy that favours speed over accuracy. Participants should respond faster but more often fail to withhold responses to No-Go stimuli. With higher Go proportions, the opportunity to correct the speed-beneficial "click" in favour of an accuracy-beneficial "check" will occur less often. Considering the two perspectives of SART performance—perceptual decoupling and response strategy—both might predict that response times to Go stimuli will decrease and errors of commission rates will increase. A proponent of the response strategy perspective would argue this is because of the relative success of the two response strategies in conditions of differing Go probability. Conversely, a proponent of the perceptual decoupling perspective may suggest this is because high proportions of Go stimuli lull participants into a more automatic disposition towards the task, which allows increased mind wandering and mindlessness.

While the two perspectives may predict manipulations of Go probability to have identical effects on response times and rate of commission errors, different predictions are made for self-reported incidences of task-related and task-unrelated thoughts. The two perspectives differ in regard to the impact of differing Go proportions on self-reports of task-related and task-unrelated thoughts. Within the perceptual decoupling perspective, a mindlessness proponent might hypothesize both task-related and task-unrelated thoughts will decrease in tasks with higher Go proportions, as the higher Go proportions would result in a reduction in overall conscious awareness (mindlessness) due to increased automaticity. Alternatively (but still within the perceptual decoupling perspective), a mind wandering proponent might suggest task-unrelated thoughts will increase and task-related thoughts will decrease with increasing Go proportions. In addition, proponents of a mind wandering perspective would also suggest a positive correlation between reports of task-unrelated thoughts and rates of commission errors and a negative relationship between task-unrelated thoughts and response time to Go stimuli. From the response strategy perspective, the person is fully aware of their ongoing performance during the task. This is evidenced by subjects "self-correcting" following errors of commission in the SART; response times increase following commission errors (Manly, Davison, Heutink, Galloway, & Robertson, 2000). Participants must be attentive to their commission errors to be able to correct for them, which they appear to do by altering their response strategy. Further, McAvinue et al. (2005) found that participants were aware of their commission errors 99.1% of the time. A proponent of the response strategy theory would suggest that increased commission errors occurring due to higher Go proportions would instead result in increased concern and thoughts regarding task performance. Reports of task-related thoughts should increase in higher Go proportion conditions, as failures to appropriately withhold are very salient. Finally, if a threshold exists wherein the pre-potent motor program disproportionately increases in efficacy after Go probability surpasses a certain level, any increase in commission errors might be best characterised as an accelerating function as opposed to a constant linear function.

4.4 Method

4.4.1 Participants

Participants were 30 (12 male, 18 female) undergraduate students from the University of Canterbury, Christchurch, New Zealand. They ranged in age between 20 and 54 years (M = 26.5, SD = 7.8). All had normal or corrected to normal vision and their participation was part of a course requirement.

4.4.2 Materials and Procedure

Participants were tested in individual workstation cubicles, seated 50 cm in front of Phillips 225B2 LCD computer screens (1680 x 1050 pixels, 60 Hz refresh rate) mounted at eye level. All stimulus and response timing were controlled using E-prime 2.0 software (Schneider et al., 2002) running on 3.40 GHz Intel i7 2600 PC computers. Head movements were not restrained. Any wrist watches were removed and mobile phones were switched off. Go/No-Go tasks that were modified versions of the SART (Robertson et al., 1997) were used. The original SART uses a Go proportion of .89 (No-Go proportion of .11). In the current experiment four variations on this proportion were used in a repeated measures design: .50, .65, .80 and .95. Each SART consisted of 208 stimuli presentations. Images of military robots (approximately 85 mm x 85 mm) were used as Go and No-Go stimuli (see Figure 4.1). One robot was an XM1219 Armed Robotic Vehicle (https://en.wikipedia.org/wiki/XM1219_Armed_Robotic_Vehicle#/media/File:FCS-

MULE-ARV-2007.jpg) and the other was a Legged Squad Support System (https://it.wikipedia.org/wiki/Legged_Squad_Support_System#/media/File:Leggedsquadsupportsystem0.png). Images were used instead of digits to provide more realism necessary for the future application of the Go/No-Go task to Shoot/No Shoot tasks (see Wilson, Head, de Joux, Finkbeiner, & Helton, 2015a) and to encourage participant engagement (see Szalma, Schmidt, Teo, & Hancock, 2014). Other authors have successfully incorporated non-digit stimuli into the SART (e.g., Smallwood et al., 2009, who used “O” as a Go stimulus and “=” as a No-Go stimulus; see also Smallwood, 2013; and Finkbeiner et al., 2015, who used picture stimuli). Two 16-item subscales of the Dundee Stress State Questionnaire (DSSQ; Matthews, Joyner, Gilliland, Huggins, & Falconer, 1999; Matthews et al., 2002) were administered to collect reported thoughts before and after the tasks. Participants answered using a 5-pt Likert scale anchored with “never” (1) and “very often” (5). One subscale measured levels of task-related thoughts while the other measured levels of task-unrelated thoughts.

Figure 4.1. The Legged Squat Support System (left) and the XM1219 Armed Robotic Vehicle (right), used as picture stimuli for the task.

After being seated at their workstations, participants completed a pre-task DSSQ. They were then informed that they would be completing four separate Go/No-Go response tasks. Through random assignment, half of participants had the XM1219 Armed Robotic Vehicle as the Go stimulus and the Legged Squad Support System as the No-Go stimulus, while the other half had the opposite. Participants’ Go and No-Go stimuli assignment remained the same for all four SARTs. Stimuli in each Go probability condition were presented in a different random order for each participant. Participants were instructed to respond, by pressing the spacebar, to Go stimuli and to withhold responses to No-Go stimuli. They were told to respond as fast and accurately as possible (speed and accuracy were emphasised equally). A practice task was administered before the first of the four trial blocks began. Practice consisted of 20 trials with a Go proportion of 50%.Verbal accuracy feedback was given after each trial. The order in which tasks were completed was random. Immediately before each task began, participants were informed of what the proportion of Go stimuli in the following task was to be. Stimuli were presented centrally on the screen for 250 ms, followed by a 900 ms mask consisting of a circle (29 mm in diameter) with a diagonal line through it (see Figure 4.2). Thus there was an 1,150 ms stimuli onset to stimuli onset interval. Responses were recorded up to 900 ms following stimuli onsets. Each task lasted approximately 4.3 min. Immediately after each task participants completed a post-task DSSQ. The whole experiment took approximately 28 min.

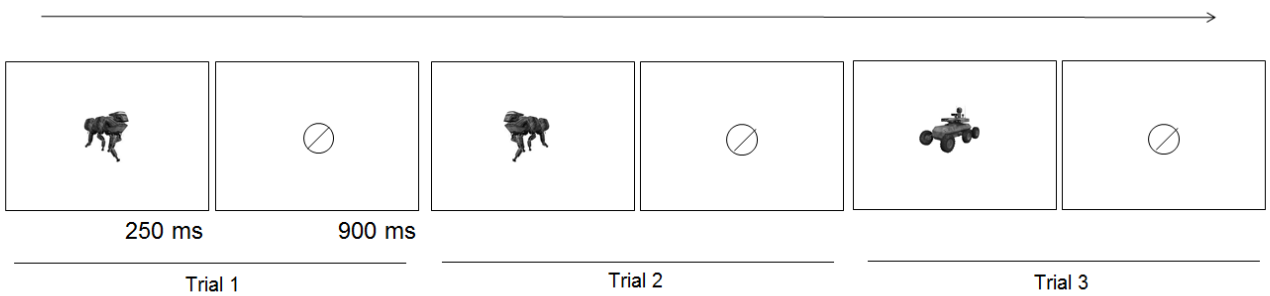

Figure 4.2 Schematic showing an example of three consecutive trials.

4.5 Results

Results from 2 of the 30 participants were removed because of excessive error rates (both omission and commission), indicating that they had failed to follow task instructions.

4.5.1 Behavioural measures

For each subject in each Go probability condition, the proportion of commission errors (Figure 4.3), the mean correct Go-stimuli response times (Figure 4.4) and the proportion of omission errors (Figure 4.5) were calculated. One-way repeated measure ANOVAs were performed separately on each of the three performance measures. The primary research focus was to test trends regarding the increase or decrease of the performance measures with increasing Go-stimuli probability (or decreasing No-Go stimuli probability). Therefore planned orthogonal polynomial contrasts (Keppel & Zedeck, 2001) were used. These are 1-df contrasts in which concerns regarding sphericity assumptions do not apply. Tests were limited to the linear and quadratic trends, as both linear and curvilinear trends were expected.

For errors of commission, there was a significant linear trend, $F(1, 27) = 319.07$, $p < .001$, $\eta_p^2 = .922$, and a significant quadratic trend in the relationship, $F(1, 27) = 10.45$, $p = .003$, $\eta_p^2 = .279$. As Go proportion increased, so did errors of commission. For response times to the Go stimuli, there was a significant linear trend in the relationship, $F(1, 27) = 236.47$, $p < .001$, $\eta_p^2 = .898$, and a significant quadratic trend too, $F(1, 27) = 37.50$, $p < .001$, $\eta_p^2 = .581$. As Go proportion increased, response times to the Go stimuli became faster. For errors of omission there was no significant linear, $F(1, 27) = .781$, $p = .384$, $\eta_p^2 = .028$, or quadratic trend, $F(1, 27) = 1.99$, $p = .170$, $\eta_p^2 = .069$.

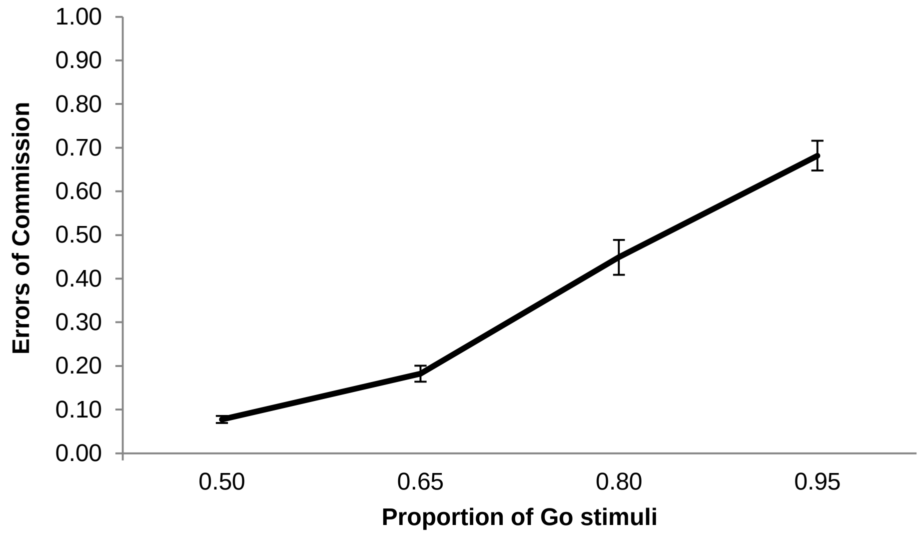

Figure 4.3. Mean proportion of errors of commission for each Go proportion. Error bars are standard errors of the mean.

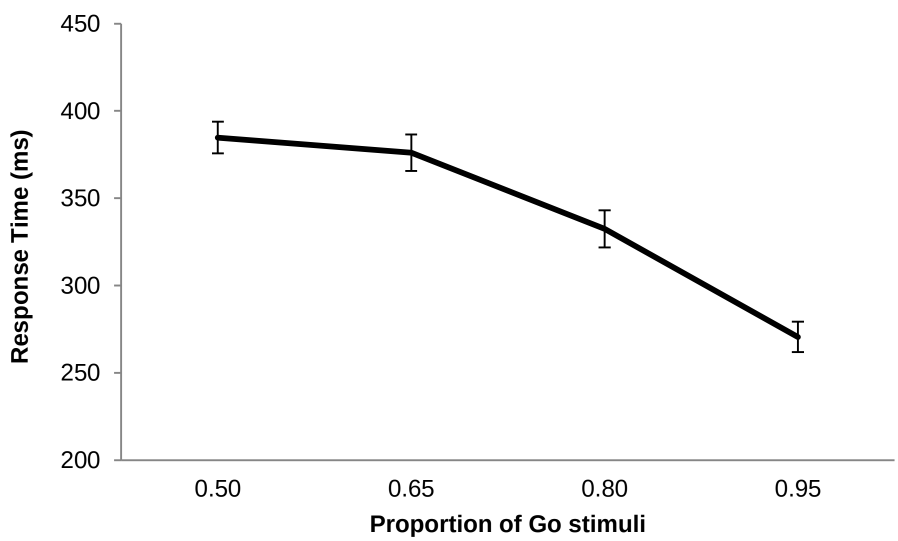

Figure 4.4. Mean response time for each Go proportion. Error bars are standard errors of the mean.

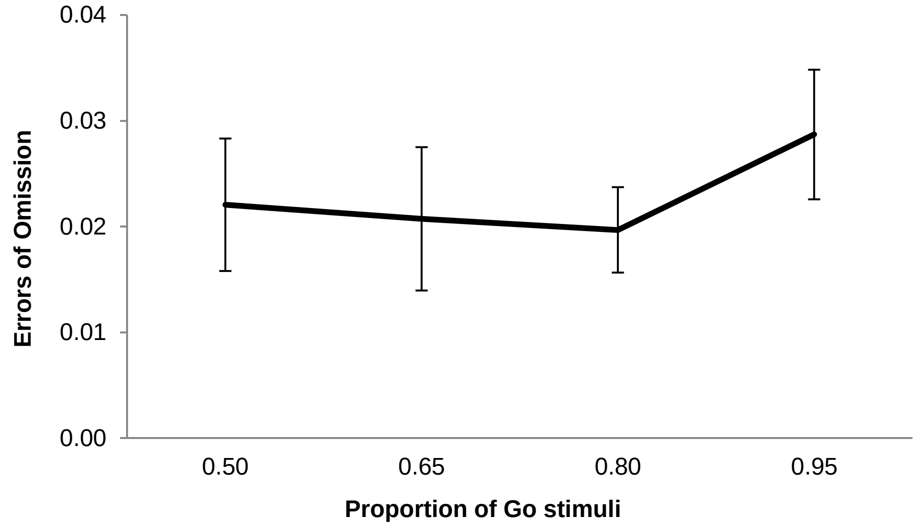

Figure 4.5. Mean proportion of errors of omission for each Go proportion. Error bars are standard errors of the mean.

To further investigate the relationship between response time and errors of commission at each Go proportion, a correlation analysis was performed with the mean commission errors and mean response times for each proportion (Table 4.1). At each proportion, the correlations are significant, $p < .01$. Furthermore, the association (r) generally increases in strength as Go proportion increases from .50 to .95.

Table 4.1. Correlation between response time and commission errors at each Go proportion.

Go proportion	.50	.65	.80	.95
Correlation (r)	-.483	-.613	-.762	-.643

Note. all $p < .01$.

4.5.2 Subjective measures

For each subject the average scores on the two DSSQ subscales (task-related thoughts and task-unrelated thoughts) were calculated, once before the tasks began (pre-task) and once after each of the four tasks, for a total of five measures. A one-way repeated measures ANOVA was performed for both subscales (see Figure 4.6 and Figure 4.7). The assumptions of sphericity were checked using Mauchly's test. This was primarily to test the pre-task questionnaire values with the post-task values. To test the differences amongst the different Go-stimuli probability conditions, planned orthogonal polynomial contrasts were used as was the case with the SART performance metrics, excluding the pre-task baseline measure.

There was a significant effect of time on task-related thoughts, $F(4, 108) = 6.32$, $p < .001$, $\eta_p^2 = .190$. Post hoc comparisons using the Bonferroni correction revealed that post-task task-related thoughts for both the .80 proportion and the .95 proportion were significantly higher than the pre-task task-related thoughts measure, $p < .01$. Polynomial contrasts with just the four different Go-stimuli probabilities revealed a significant linear trend, $F(1, 27) = 5.03$, $p = .033$, $\eta_p^2 = .157$, with task-related thoughts increasing with increasing Go probability. For task-unrelated thoughts, there was a significant effect of time, $F(4, 108) = 25.93$, $p < .001$, $\eta_p^2 = .490$. Post hoc comparisons using the Bonferroni correction revealed that all of the four post-task task-unrelated thoughts measures were significantly lower than the pre-task task-unrelated thoughts measure, $p < .01$. Polynomial contrasts with just the four different Go probabilities failed to show any significant trends. However, while not statistically significant, a potential linear relationship was observed in the direction of decreasing task-unrelated thoughts with increasing Go probability, $F(1, 27) = 2.88$, $p = .101$, $\eta_p^2 = .096$.

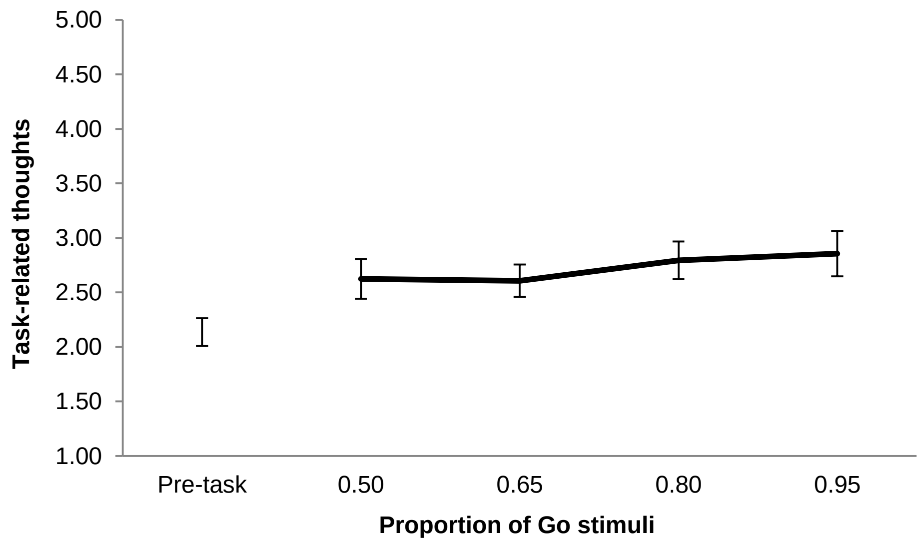

Figure 4.6. Mean task-related thoughts for each Go proportion. Error bars are standard errors of the mean.

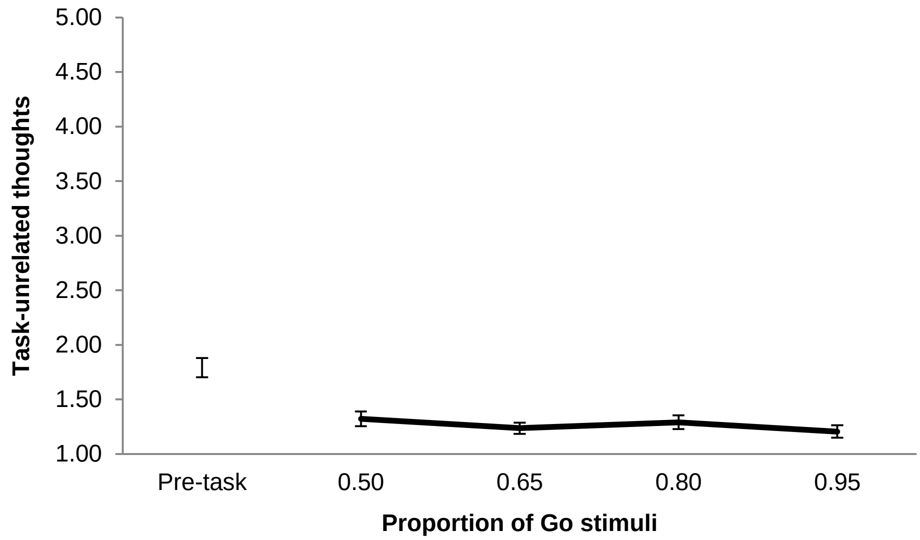

Figure 4.7. Mean task-unrelated thoughts for each Go-stimuli proportion. Error bars are standard errors of the mean.

4.5.3 Relationship between behavioural and subjective measures

Both between-subjects and within-subjects correlations were investigated through the use of an established technique (see Head & Helton, 2014; Zelenski & Larsen, 2000). To investigate between-subject correlations each participant's performance metrics on the SART and their self-report responses (i.e., their mean average value for a condition) were averaged over the four conditions and then the correlations between these individual averages were calculated. Between-subject correlations isolate the differences that can be attributed solely to trait individual differences after removing within-subject variance. To investigate within-subject correlations, for each condition each participant's performance metric and self-report responses were converted to *standardized within-subject z-scores* (see Head & Helton, 2014; Zelenski & Larsen, 2000) resulting in 4 response time *z*-scores, 4 commission error *z*-scores, and so on for each of the metrics and questionnaire responses. The resulting *z*-scores were then combined (chained; for other examples of using combined or "chained" z-scores to calculate within-subject *z*-scores see Head & Helton, 2014; and Helton, Funke, & Knott, 2014) across participants for the analysis. Table 4.2 displays the results of these analyses.

Table 4.2. Correlations between variables (within-subjects above main diagonal; between-subjects below main diagonal).

	EC	EO	RT	TRT	TUT
Errors of commission (EC)		.144	-.920**	.296**	-.188
Errors of omission (EO)	.027		-.107	.152	.164
Response time (RT)	-.784**	.209		-.295**	.184
Task-related thoughts (TRT)	-.397*	-.437*	.229		-.092
Task-unrelated thoughts (TUT)	-.363	-.265	.170	.319	

* $p < .05$ and ** $p < .01$, for an N of 28.

Errors of commission were significantly correlated with response time both within-subjects and between-subjects. At the within-subjects level, when a participant quickened their own rate of responding they were more likely to make a commission error themselves, and equally at the between-subjects level participants who generally responded faster than other participants were also more likely to make more commission errors on average. Errors of commission were significantly positively correlated with task-related thoughts at the within-subjects level. When participants experienced an increase in thoughts about the task, this coincided with an increase in commission errors. At the between-subjects level this result was reversed, with participants who reported higher task-related thoughts generally making fewer errors of commission. This was similarly seen with errors of omission, where participants who reported higher task-related thoughts also generally made fewer omission errors. Finally, at the within-subjects level increases in task-related thoughts were associated with faster responses to Go stimuli. Task-unrelated thoughts shared no significant relationships with any of the measures.

4.6 Discussion

The current experiment investigated how performance on a high Go, low No-Go task and associated thought content changed as Go proportion was manipulated across four conditions: .5, .65, .80, and .95. Errors of commission, errors of omission, and response times were taken to gauge SART performance, while two subscales of the DSSQ—task-related thoughts and task-unrelated thoughts—were used to measure self-reported thoughts.

The finding that as Go proportions increased, response times decreased and commission errors increased could be accounted for by both the perceptual decoupling theory and the response strategy perspectives. According to the perceptual decoupling theory, higher proportions of Go stimuli should have lulled subjects into an automatic mode of responding, resulting in either increased mindlessness or mind wandering. However, contrary to perceptual decoupling instead of task-related thoughts decreasing as Go proportion became higher, they increased. Participants were evidently attentive to the task, and therefore perceptually *engaged* rather than decoupled. Instead of task-unrelated thoughts increasing, as the perceptual decoupling view might predict, they appeared to actually decrease as Go proportion increased. However it should be noted that one interpretation of the perceptual decoupling model (mindlessness) might have successfully predicted the reduction in task-unrelated thoughts, but would have also predicted a decrease in task-related thoughts as well (true mindlessness—as in no conscious thoughts). Nonetheless, if participants had been perceptually decoupled from the task and engaged with mind wandering, task-unrelated thoughts should have been positively associated with errors of commission and negatively associated with response time. Conversely, correlation analyses showed that task-unrelated thoughts shared no statistically significant relationship with commission errors or response times at either the within-subject or the between-subject level, and all four post-task measures of task-unrelated thoughts were significantly lower than the initial pre-task measure. Although not statistically significant, the direction of the correlations between task-unrelated thoughts and errors of commission and response times were actually in the opposite direction. Participants who reported more task-unrelated thoughts actually tended to make fewer commission errors (and this was true both within- and between-subjects). To the contrary, it was task-related thoughts that were significantly associated with errors of commission and response times at the within-subject level and with errors of commission at the between-subject level. This reflects the involvement or entanglement of the speed–accuracy trade-off with participants' thoughts about the task and this has also been seen in previous research with the SART (Wilson et al., 2015b). As to the cause of this relationship, it could be that participants who think more about the task then speed up their responding in an attempt to perform even better, but in doing so they inevitably have more difficulty withholding to the No-Go stimuli and thus make more commission errors. Or perhaps the act of making commission errors causes them to think more about the task (e.g., performance appraisal). Neither explanation fits with the perceptual decoupling idea. Instead, these explanations indicate participants' conscious engagement with the task, and are consistent with the idea that people are aware of the errors they make and that their response times over the task are contingent upon this awareness.

The differential effects that the varying Go proportions had on commission errors and response time can be accounted for by the ACT-R model (Anderson & Lieberman, 1998). The different Go proportions each offered different opportunities in terms of the ideal response strategy for a given proportion. As expected, at higher Go proportions participants favoured the less conservative response strategy, evidenced by faster response times at the cost of more commission errors, whereas at lower Go proportions participants used the conservative strategy more often, demonstrated by slower response times but fewer commission errors (Peebles & Bothell, 2004).

The trend analyses provide a degree of support for the idea that a threshold exists wherein the feed-forward pre-potent motor program disproportionately increases in strength, leading to an abrupt shortening of response times and increase in commission errors. Commission errors had a curvilinear trend, whereby they initially gradually increased as Go proportion became higher, but then increased markedly over the higher proportions, showing a similar pattern to that seen by Wilson et al. (2014; Chapter 2). In their experiment they were unable to measure response times for individual trials however, so the finding that in the present study response time exhibited a curvilinear trend and appeared to have an inverse relationship with errors of commission is notable. For the participant, a pre-potent motor response ensures that the response is fast and without delay, however it also makes withholding responses (when required) more difficult and therefore less likely. This is not the first time that an inverse relationship between speed and accuracy in the SART has been found. Head and Helton (2014) observed that SART performance oscillated over sessions spaced apart by a number of weeks. In sessions where participants tended to respond more slowly they made fewer commission errors and conversely in sessions when they responded faster they made more commission errors. In the current experiment, the decreases in response time appeared to inversely mirror the increases in commission errors, with the biggest decrease between conditions appearing to occur between the .65 and .80 Go proportions. This appeared to be reflected in the self-reported thoughts too. A visual inspection of the data for task-related thoughts (see Figure 4.6 in results) suggested that the increase over Go proportions was primarily due to a rise specifically between the .65 and .80 proportions. Tests of this did not reach statistical significance however, although other tests did show that the only conditions where task-related thoughts were significantly higher than the pre-task baseline were the .80 and .95 proportions. In terms of the strength of the relationship between response time and commission errors at each Go proportion, correlation analyses demonstrated that these associations generally became stronger as Go proportion went from .50 to .95.

There is practical value in understanding the effects that Go proportion has on pre-potent motor responses. In operational environments, being able to predict when a pre-potent response may abruptly intensify in an environment where a human is responding often and withholding responses less often, could be important information. For instance, a military or law enforcement commander may be able to use this knowledge to recognise when weapons operators are at a higher risk of committing friendly fire errors (see Wilson, Head, & Helton, 2013b). Nonetheless, it should be noted that tests for linear trends for response times and commission errors were also statistically significant in the current experiment, and further investigation of the disproportionate change in the SART performance metrics is required. Furthermore, there are obvious differences between an operational context in the military and the computer-based laboratory task completed by participants here. For instance, participants in a battle are typically unaware of the proportion of foes relative to friends or non-combatants they can expect to confront (although they may have some idea based on prior intelligence or assumption). Moreover, "stimuli" may be encountered at highly irregular intervals as opposed to the strict timing employed in the task here. Controlling conditions as has been done here is required to rule out potentially-confounding variables. Whether factors such as knowledge of foe proportion and regularity of inter-stimulus intervals have an impact on failures to withhold fire is interesting however and it would be highly useful to investigate this. In the case of varying irregular inter-stimulus intervals, the findings from Chapter 2 suggest that even with highly variable intervals people operating firearms will make response inhibition errors in high-foe situations. In the experiment here, the time between which a participant confronted one confederate followed by the next (inter-stimulus interval) varied substantially (between approximately 2 and 15 seconds), suggesting the irregular intervals soldiers in battle will face may not alleviate inhibition errors.

Correlation analyses revealed strong negative relationships, at both the within- and between-subjects level, between errors of commission and response time, the speed–accuracy trade-off. Errors of omission shared no association with response time and commission errors. There was however a significant negative correlation between task-related thoughts and omission errors and commission errors at the between-subject level. People who tended to report more task-related thoughts tended to make fewer errors of omission and fewer errors of commission. Task-related thoughts were positively correlated with errors of commission and negatively correlated with response time at the within-subjects level. When people reported more task-related thoughts they tended to make more errors of commission and had faster response times. This is likely due to common fate with increasing Go stimuli probabilities; increases in task-related thoughts were linked with increasing Go proportions and probably occurred independently of the changes in the behavioural metrics. In other words, the change in task-related thoughts was likely a product of the increase in Go proportion, and not the behavioural metrics. Further research into this may be useful however. Participants tended with high Go probabilities to respond faster, make more errors of commission, and report more task-related thoughts.

Further research is needed to disentangle the nature of the notable decrease in people's ability to withhold in Go/No-Go tasks, which appears to be closely related to the proportion of Go to No-Go stimuli and the response strategy used. In terms of the proportions that researchers should consider employing, using more intervals within the .5 to 1.0 Go proportions should help to determine or narrow down the proportions of particular interest. A useful addition may also be a condition where 100% of responses required are Go responses. This will enable a "floor" response time to be established. Perhaps at a Go proportion of .95, the highest proportion employed here, participants are very close to a floor response time and physically at their limits anyway. Although the fact that participants in this .95 proportion condition were still able to occasionally withhold responses to No-Go stimuli, albeit only around 30% of the time, suggests their limits can be pushed further.

In the current experiment participants appeared to adopt the response strategy that provided the most usefulness for each of the differing Go proportions. In a high Go task such as the SART, response inhibition appears to be dictated by response strategy, and this in turn seems to be determined by, or at least strongly influenced by, Go proportion. This relationship may become stronger when a virtual "breaking point" or threshold is surpassed. This threshold appears to be somewhere between the .65 and .80 Go proportion. The functional relationship between Go proportion and errors deserves further exploration. The findings of this research provide further evidence that performance on the SART, and perhaps by extension high Go, low No-Go tasks, is heavily influenced by response strategy and response inhibition. Sustained attention may nevertheless contribute to performance on the task, however this may involve a form of internally-directed attention (executive control is required to regulate response strategies) as opposed to externally-directed attention (for which failures can be thought of as perceptual decoupling). Researchers who intend to measure externally directed attention would be better served by using a different tool than the SART. The SART may be a useful tool for other purposes however, such as modelling behaviour in shoot/no-shoot scenarios (Wilson et al., 2013b, 2015a). The SART appears to measure a different cognitive construct (response strategy) than what many researchers are currently intending to measure (sustained attention). The findings here cannot easily be explained from a perceptual decoupling perspective. More specifically the mind wandering interpretation of performance errors in SART-like tasks requires closer scrutiny. The current findings are consistent with a theory of strategic responding in the SART. How consciously reported thoughts influence strategy choice in the SART-like tasks remains a topic for future research.

4.7 Summary

The impact that Go proportion had on performance in a modified SART was investigated using a computer-based SART with four different proportions of Go stimuli. The impact of Go proportion on response times and inhibition errors appears to be non-linear. The largest differences between Go proportions came between the .65 and .80 proportions. Proportions of Go stimuli greater than .65 may be needed to establish a strongly pre-potent motor response routine that gives rise to disproportionate shortening (disproportionate to increases in Go proportions) of response times and a marked increase in failures to withhold responses, that is commission errors. This could have important implications for military personnel wishing to identify environments where the risk of friendly fire may be particularly high. When weapons operators are in situations where they are firing at around 80% (or higher) of the individuals they encounter on a battlefield, they may develop pre-potent motor response routines which increase their likelihood of accidentally firing at friends or civilians. This Chapter also incorporated thought measures to compare two different interpretations of SART performance: perceptual decoupling versus response strategy and response inhibition. The results suggested performance was subject to competing response strategies which participants used as opposed to varying degrees of absentmindedness or perceptual decoupling.

In sum, the proportion of Go stimuli has a substantial impact on response inhibition in the SART and perhaps in weapons operations too. While this could be useful information for a military commander who wishes to identify high-risk environments for friendly fire accidents, it will not always be possible to avoid these environments. Furthermore, altering Go proportion will often not be a feasible option for someone faced with a high Go task that could induce response inhibition failures. Therefore, other avenues that could prevent motor response inhibition errors need to be explored. One such avenue could involve artificially delaying responses by increasing the time it takes to physically execute responses. Prior research suggests this improves response inhibition in SART-like situations (Head & Helton, 2013). Chapter 5 presents a study which explores this as well as the two different perspectives of performance in SART-like contexts.

5 Shortening the Physical Response in SART-like Tasks Exacerbates Pre-potent Motor Responding

5.1 Rationale

The current Chapter features a modified SART experiment where the mode of physical response method is altered. Changing physical or motor aspects in SART-like situations provides a means to assess the impact that increasingly automated systems, such as automated weaponry, may have on the likelihood of friendly fire errors. As weapons systems become more automated, typically the motor actions required to fire these weapons will involve shorter-distance hand or finger movements (Helton & Kemp, 2011). While this may reduce the time required to fire or make responses, it could heighten the chances of firing accidentally (e.g., friendly fire).

Changing physical aspects of the required response provided another way to compare the two competing perspectives of performance in SART-like tasks. Reducing the physical demands required to execute responses in a modified SART should artificially shorten response times, leading to greater commission errors. By having subjects also report their mental and physical demands and fatigue, whether any decrease in performance is related to reduced cognitive engagement with the task (as a proponent of the perceptual decoupling theory may posit) or simply the altered physical aspects (consistent with a response strategy perspective) can be examined.

5.2 Abstract[4]

Automated weapons systems are rapidly becoming more common. Technological advances have enabled aspects of the weapon firing process, which originally required human involvement, to now be carried out at a sufficient standard by robots. While this may offer several benefits, it could also present risks such as an increased likelihood of friendly fire. In two tasks whether or not a mouse cursor required movement in order to respond to stimuli was manipulated (automatic movement versus manual movement by the subject). Additionally, stimuli were located at either a close or a far distance away. Commission errors, or friendly fire, were inversely related to distance in the manual movement task, as the farther distance led to longer response times which gave participants more time to inhibit pre-potent 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 task; instead the differences were primarily in physical demands. The movement effect combined with participants' subjective reports are evidence for time dependent action stopping, not greater cognitive engagement. These findings suggest that as weapons become more automated, the risk of friendly fire incidents will increase. Further, the findings support a response strategy perspective as opposed to a perceptual decoupling perspective.

5.3 Introduction

Adaptations of the basic Sustained Attention to Response Task (SART; Robertson et al., 1997) have recently been used to investigate soldier behaviour in a battlefield environment, where small arms simulations were conducted to simulate dismounted soldiers in close quarters combat (Wilson et al., 2013b; 2014; 2015a). The SART may also be usefully adapted to further understand other shoot/no-shoot decisions in a battlefield environment. The use of automated weapons is one such example. Investigating how an automated versus a non-automated response affects response inhibition is important, particularly as automated systems become more ubiquitous. While automating aspects of a task can have the benefit of—among other things—reducing the time required to complete the task, it may also make actions more difficult to prevent on occasions when prevention is necessary. In a military context for example, advanced weaponry systems that can automatically detect and aim at targets are being developed. Reportedly, at least 44 countries are currently developing military robotics (Hood, 2015). The United

[4] Submitted paper. This chapter is based on: Wilson, K. M., de Joux, N. R., Finkbeiner, K. M., Russell, P. N., & Helton, W. S. (submitted, September 2015). Buying time to inhibit the feed-forward ballistic motor program in the Sustained Attention to Response Task.

States Army currently uses a “human-in-the-loop” model with regard to the initiation of lethal force, showing that the role of the human operator is still considered to be crucial. However, new automated weaponry systems will likely instead compromise control between the human and the automation (Asaro, 2012). Some weaponry systems developed elsewhere have already surpassed this level of automation though. The “Super aEgis II” developed by South Korean defence firm DoDAAM, and Samsung’s SGR-A1, are both able to identify and lock on to targets without any involvement from human operators (Egeland, 2004).

Systems with automatic target recognition will often remove the need for a human operator to both detect the target and then aim at the target by physically moving the weapon to aim towards it. Instead the operator may only be required to pull a trigger, or push a button, to deploy the weapon. The result is that an operator could be faced with a stream of targets appearing on a screen, requiring them to make rapid shoot/no-shoot decisions to targets they have little knowledge about (Asaro, 2012). Furthermore, as noted by Asaro the nature of such a role may tempt organisations to use people with less training. Helton & Kemp (2011) suggest that the fast, easy and short-distance hand movements that some unmanned vehicle weaponry systems may offer (see Figure 5.1.) could make operators more vulnerable to committing friendly fire errors due to motor response inhibition failures. Indeed, the role of a pre-potent motor response routine in the use of weapons has already been observed (Wilson et al., 2015a).

Figure 5.1. A pilot controls an MQ-1 Predator unmanned aerial vehicle.

The role of motor response inhibition in the SART has been well-established (Helton, 2009; Seli et al., 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 et al., 1999; Robertson et al., 1997) or mind wandering (Smallwood & Schooler, 2006).

An alternative perspective is that commission errors in SART-like situations are not a reflection of mind wandering, mindlessness, or losses of sustained attention, but rather the result of choice of response strategy or response inhibition. Peebles and Bothell (2004) presented an ACT-R model (Anderson & Lieberman, 1998) which is able to predict the association between response times to Go stimuli and commission errors in participants' SART performance. Their model incorporates two competing response strategies, one which favours speed at the cost of accuracy and the other which favours accuracy at the cost of speed. The high Go, low No-Go nature of SART situations increases the perceived value of the faster but less accurate strategy. This appears to encourage the development of a ballistic feed-forward motor program which increases in strength (Head et al., 2012; Helton et al., 2005). The SART is highly conducive to the development of this motor program, because of the constant quick pressing which is required of subjects (Doyon, Penhune, & Ungerleider, 2003). Motor programs can be beneficial because they may make a highly-used response more efficient (e.g., faster and requiring less effort) but in high Go, low No-Go situations, such as the SART, they lead to high rates of commission errors.

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 & Helton 2012). Furthermore, participants often report increases in task-related thoughts and decreases in task-unrelated thoughts (Wilson et al., 2015b). 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 et al., 2009). Participants are aware of their commission errors 99.1% of the time (McAvinue et al., 2005). Performance in SART-like situations does not appear to be associated with mindlessness, mind wandering, or lack of attention to the stimuli.

Performance in SART-like situations is influenced by a number of factors which clearly support a response strategy explanation of performance (Finkbeiner et al., 2015; Helton et al., 2011a, 2011b). Recently, altering the response format by increasing the time that was required to physically make a response was also shown to reduce commission errors. Head and Helton (2013, 2014) 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 response times, which appeared to allow participants time to inhibit the pre-potent motor response and consequently they made fewer commission errors. Whether this result is in fact due to participants having more time to prevent pre-potent motor responses is uncertain however. Perhaps the physical component of the additional manual movement simply reduced 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 "under-load," 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 promoting participants' attention (Johnson et al., 2007), which, according to this perspective, could lead to a lower rate of commission errors.

The current experiment, manipulated both the movement (acquisition) required to make responses to stimuli (as done by Head & Helton, 2013) as well as the distance of stimuli locations from a central point. Concerning stimuli acquisition, in one task—'manual selection'—following the appearance of a Go stimulus participants were required to physically move the mouse cursor to a box containing the stimulus before they could make a click response so that responses could only be made when the cursor was inside the correct box. This represents a weapon system with little to no automation; the operator is required to detect the target him or herself, and then physically aim towards the target before being able to respond or fire. In the other task—'automatic selection'— no movement of the mouse cursor was required. Instead participants had to simply press a mouse button (click) when a Go stimulus appeared in a box. This represents a contemporary automated weapon system where target detection as well as aim is completed by the software (e.g., automatic "lock on" to targets or target acquisition). This is also 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 centre at close and far distances, while the cursor was always at the centre of the screen at the beginning of each trial. This enabled the measurement of the effects of target distance (close vs. far) on commission errors and response time.

In the manual task, the additional physical action of moving the mouse cursor to firstly select the stimulus, before a click response could be made, should slow participants' responses. This should improve their ability to withhold responses to No-Go stimuli. If increasingly automated weapons systems may indeed pose a risk to accidental shootings though, participants should struggle to withhold responses to targets in the automatic task.

Stimuli locations were also varied. Location distance was not expected to affect performance in the automatic task but in the manual task it was expected that commission errors will be fewer when movement extent is greater. This would provide further evidence that the improved performance offered by the manual movement is caused by efferent response factors rather than perceptual factors such as cognitive engagement; while the need to move a bit farther offers a physical difference it should not be much different *perceptually*.

In terms of the competing explanations of performance in SART-like situations, both the perceptual decoupling and the response strategy perspectives predict that participants will take longer to respond to stimuli in the manual selection task and make fewer errors of commission relative to the automatic task. From a strategic or motor inhibition view, 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 pre-potent 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 further 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 the distance condition on performance.

It was predicted that commission errors would be inversely related to distance in the manual selection task, but not in the automatic selection task. 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 response times, participants should make fewer commission errors, because the longer response times 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 less perceptual decoupling from the stimuli. Regardless, varying the extent of movement 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 each followed by two self-report scales that gauged thoughts and workload. The self-report thought and workload scales were predicted to reflect the additional physical demands of the manual selection task but yield no differences between the mental demands of the manual versus the automatic selection task, in line with the response strategy or inhibition perspective. Advocates of a mindlessness or perceptual decoupling perspective of the SART would more likely predict large differences in self-reported task-unrelated thoughts between the manual and automatic SARTs.

5.4 Methods

5.4.1 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.

5.4.2 Materials

Participants were tested in individual workstation cubicles, seated 50 cm in front of Phillips 225B2 LCD computer screens (1680 x 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 (Schneider et al., 2002). Screens were mounted at eye level and participants did not have their head movements restrained. In a within subjects design, participants completed two different Go/No-Go response tasks that were modified versions of the SART (Robertson et al., 1997). The two SART versions differed in the movement (between-task; manual versus automatic) that participants were required to perform to make responses. For both movement tasks, four boxes (each 60 mm x 60 mm), serving as possible locations for the stimuli, were displayed on the screen during the task and were arranged horizontally (see Figure 5.2) in the vertical centre of the screen. A fixation cross (6 mm x 6 mm) was visible in the centre of the screen at the onset of each trial. A second manipulation was present within both of the movement tasks: distance (within-task; close versus far). To the immediate left and right of the fixation cross was a ‘close’ box centred 55 mm from the screen centre and a ‘far’ box centred 150 mm from the screen centre. On each side the distance between the close and the far box was 95 mm. Close and far trials were randomly intermixed within each of the two tasks. For each of the two tasks subjects completed 252 trials in which Go probability was .89 and No-Go probability was .11. For each trial a stimulus appeared in one of the four boxes. In the manual response task, at the onset of each stimulus the fixation cross was replaced with a cross hair, which was similar in shape to the fixation cross except larger (10 mm x 10 mm). The change to the crosshair served as a cue for the participant, indicating that they now had manual control over the crosshair. Participants were required to manually shift the crosshair from the central point to the box containing a stimulus. Once the crosshair was positioned in a box, the box’s borders became bolded (thicker), indicating that the box had been selected. To complete the response participants were required to click the mouse. Participants were not required to move the crosshair after they had made a response; the crosshair automatically moved back to the central point at the end of each trial. In the automatic task participants were not required to move the mouse at the onset of a stimulus; the stimulus was automatically selected (again indicated by the borders becoming bolded). To complete a response in this task, participants had only to click the mouse button. Mouse movement was disabled in the automatic task. A Microsoft Wheel Mouse Optical was used to move the cursor (manual task only) and to perform the click (both tasks).

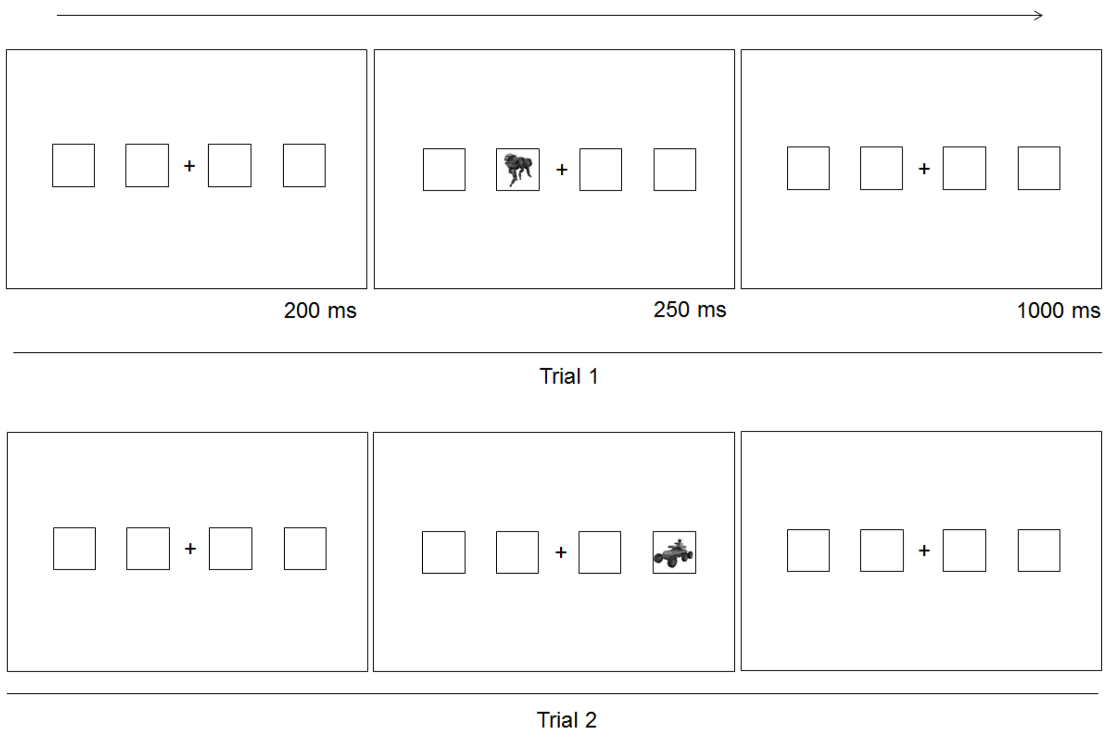

Figure 5.2. Schematic showing an example of two consecutive trials.

Two self-report questionnaires were used. One was an 11 item stress scale (see Blakely, 2014) where each item was based on factors from the DSSQ (Matthews et al., 2002). Items were ranked on a Likert scale of 0 (“very low”) to 100 (“very high”) and included: physical fatigue, mental fatigue, tense, unhappy, motivation, task interest, self-related thoughts, concentration, confidence, task-related thoughts, and task-unrelated thoughts. The second scale was a modified version of the NASA-TLX scale (Hart & Staveland, 1988) used to gauge subjective workload. This version was determined via prior factor analyses (see Bailey & Thompson, 2001; Ramiro et al., 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, 2015; Hancock, 2015; Sellers, Helton, Näswall, Funke, & Knott, 2014). A global workload measure, which was the combined average of the responses to the NASA-TLX subscales, was also computed for each participant on each task.

Stimuli were two computer-generated images of robots (approximately 85 mm x 85 mm) also used in Chapter 4. One was an XM1219 Armed Robotic Vehicle and the other was a Legged Squad Support System (see Figure 4.1, p. 50). These were sized to fit inside the boxes and so shared the same dimensions as the boxes. Images were used instead of digits to provide more realism necessary for the application of the task to Shoot/No shoot tasks (see Wilson et al., 2015a) and to encourage participant engagement (see Szalma et al., 2014). Through random assignment, half of participants had the XM1219 Armed Robotic Vehicle as a Go stimulus and the Legged Squad Support System as a No-Go stimulus (for both tasks), while this allocation was reversed for the other half of participants. Participants' allocation was the same for both tasks 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 task, 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 response times to Go stimuli. Cursor movements in the manual task were also tracked by recording the X and Y co-ordinates of the mouse cursor every 25 ms.

5.4.3 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 = .89) and to not respond to No-Go stimuli (p = .11). Participants were told to place equal emphasis on speed and accuracy. Before each of the two tasks participants were informed which robot to respond to and which to make no response to. They were then told whether they would be required to manually move the crosshair to the stimulus box (manual task) on each trial or simply to respond (automatic task) when a Go stimulus occurred. For the manual task, 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 task, participants were instructed to respond to Go stimuli by simply clicking the mouse button when Go stimuli appeared. Participants completed 36 practice trials appropriate to the movement task before each block of main trials. They were given verbal accuracy feedback during the practice trials.

In both tasks, 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 1,000 ms (see Figure 5.2). Thus the total onset to onset interval was 1,450 ms. Responses were recorded up to 1,000 ms after stimulus onset.

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

5.5 Results

5.5.1 Behavioural measures

For each subject in each condition, manual and automatic (selection) and close or far (distance), the proportion of commission errors, proportion of omission errors, the mean correct Go stimuli response times, and proportion of times participants moved the crosshair into boxes ("box entries") containing No-Go stimuli were calculated. These data are presented in Table 5.1. Firstly though, it was checked that participants had been given enough time to make responses in the manual condition, given that participants were required to move their mouse into a box before responding. The average response times in the manual condition (see Table 5.1) were indeed well below the 1,000 ms provided to make responses, and participants failed to make responses on Go trials on just 1.1% of occasions.

Table 5.1. Performance for each condition.

	Automatic		Manual	
	Close	Far	Close	Far
Response time	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)

Note. Values within parentheses represent standard deviations.

To explore the differences between the conditions, separate 2 (selection: manual vs. automatic) x 2 (distance: close vs. far) repeated measures ANOVAs were performed on each of the three performance measures and these were followed up with paired *t*-tests when necessary.

For response times, there was a main effect of selection, wherein manual (M = 560.6, SD = 58.2) selection was significantly slower than automatic (M = 341.2, SD = 40.5) selection, $F(1, 40) = 601.5$, $p < .001$, $\eta_p^2 = .938$. There was also a main effect of distance, with responses to far (M = 489.6, SD = 43.7) distance significantly slower than close (M = 412.2, SD = 40.2) distance, $F(1, 40) = 935.5$, $p < .001$, $\eta_p^2 = .959$. There was also a significant selection x distance interaction, $F(1, 40) = 494.0$, $p < .001$, $\eta_p^2 = .925$. Paired *t*-tests revealed that the manual–far condition had significantly longer response times than manual–close, $t(40) = 29.5$, $p < .001$, $d = 4.61$, and equally, automatic–far had longer response times than automatic–close, $t(40) = 13.27$, $p < .001$, $d = 2.07$. Response times to the far distance were longer in both selection modes, however a closer inspection of the results in Table 5.1 as well as the 95% confidence intervals suggest that the response time difference between close and far was much more substantial in the manual selection mode, $M_{difference}$ = 127.27, 95% CI [118.55, 135.99], than the automatic selection mode, $M_{difference}$ = 27.39, 95% CI [23.22, 31.56].

For errors of commission, there was a main effect of selection, $F(1, 40) = 216.3$, $p < .001$, $\eta_p^2 = .844$, with fewer errors made in manual ($M = .03$, $SD = .06$) than automatic ($M = .40$, $SD = .18$). There was no main effect of distance (close $M = .22$, $SD = .14$; automatic $M = .22$, $SD = .10$), $F(1, 40) = .003$, $p = .959$, $\eta_p^2 = .000$, however there was a significant interaction between selection and distance, $F(1, 40) = 6.17$, $p = .017$, $\eta_p^2 = .134$. This interaction was followed up with paired *t*-tests. Manual–far had significantly fewer commission errors than manual–close, $t(40) = 3.05$, $p = .004$, $d = 0.476$, but there was no significant difference between automatic–far and automatic–close, $t(40) = 1.20$, $p = .238$, $d = 0.187$. Distance did not appear to be a factor in the automatic task, yet in the manual task 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 in the far ($M = .011$, $SD = .01$) distance than to stimuli in the close ($M = .006$, $SD = .01$) distance, $F(1, 40) = 8.07$, $p = .007$, $\eta_p^2 = .168$. There was no difference between omission errors for manual ($M = .011$, $SD = .01$) versus automatic ($M = .006$, $SD = .02$) selection modes, $F(1, 40) = 2.05$, $p = .160$, $\eta_p^2 = .049$, however there was a significant interaction between distance and selection, $F(1, 40) = 12.30$, $p = .001$, $\eta_p^2 = .235$. Paired *t*-tests showed that there was a difference within the manual task, with significantly more omission errors made to far than to close, $t(40) = 3.66$, $p = .001$, $d = 0.572$, but no difference within the automatic task, $t(40) = .72$, $p = .474$, $d = 0.113$. The greater number of omission errors to far stimuli than close stimuli was therefore due to a difference within the manual task. Participants may have had insufficient time to complete movements in the manual–far condition, however these numbers are very low (omission errors occurred on just 1.1% of Go trials) and the lack of a significant difference between the automatic condition (where no movement was necessary) and the manual condition suggests this is not the case.

It was noted that errors of commission were relatively rare in the manual selection task (although a paired *t*-test showed that fewer commission errors were made to far stimuli than to close stimuli within the manual task). 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 task, 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 25 ms during the trial were examined. Through this it was apparent that while participants in the manual task had successfully withheld responses to most No-Go stimuli, they had nevertheless often moved the crosshair to the box containing the No-Go stimulus. On average, participants moved the crosshair into the No-Go stimulus box on 70% of the time. This could provide further insight into how participants' ability to withhold was affected by manual selection as well as distance (see

Table 5.1). As only the manual task 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 = .61, SD = .17) than to close boxes (M = .79, SD = .16), $t(40) = 5.80$, $p < .001$, $d = 0.905$.

5.5.2 Correlations between response time and errors of commission

Pearson product correlation coefficients were used to analyse the relationships between response time and commission errors for each of the conditions (N = 41 in all cases). There was a significant negative correlation between response time and commission errors in the automatic task, $r = -.552$, $p < .001$, as well as in the manual task, $r = -.371$, $p = .017$, albeit smaller. Both tasks were then broken down to investigate distance as well (Table 5.2). There were significant correlations indicative of speed–accuracy trade-offs at every condition except for the manual–far condition.

Table 5.2. Correlations (r) between response time and errors of commission for each condition.

Manual–close	Manual–far	Automatic–close	Automatic–far
-.42**	-.09	-.50**	-.48**

** $p < .01$

5.5.3 Subjective measures

Each participant's mean subjective ratings of each item on both the Stress Scale (Table 5.3) and the modified NASA-TLX (Table 5.4), for both the manual and automatic selection tasks were calculated. Scores for close versus far distance could not be analysed here because close and far trials occurred randomly within the manual and automatic trial blocks. Paired samples *t*-tests were conducted to see how selection affected each of the subjective ratings.

Table 5.3. Stress Scale ratings for the manual and automatic tasks.

	Manual	Automatic	*d*
Physical Fatigue*	4.12 (2.72)	3.24 (2.70)	.358
Mental Fatigue	4.95 (2.85)	5.00 (2.84)	.022
Tense	3.95 (2.93)	3.93 (2.50)	.013
Unhappy	2.85 (2.52)	3.41 (2.73)	.302
Motivation	6.17 (2.10)	5.76 (2.35)	.205
Task Interest	4.02 (2.41)	3.46 (2.63)	.246
Self-related Thoughts	3.20 (2.10)	3.39 (2.13)	.088
Concentration**	7.00 (1.83)	6.17 (2.11)	.559
Confidence**	6.71 (1.66)	5.76 (1.53)	.585
Task-related Thoughts*	7.00 (2.07)	6.22 (2.04)	.350
Task-unrelated Thoughts	4.20 (2.65)	4.71 (2.27)	.199

Note. Values in parentheses represent standard deviations. ** $p < .01$, * $p < .05$.

Table 5.4. NASA-TLX ratings for the manual and automatic tasks.

	Manual	Automatic	*d*
Physical Demand**	3.39 (2.01)	1.71 (1.68)	.837
Mental Demand	5.83 (2.26)	5.39 (2.31)	.299
Temporal Demand	5.66 (2.15)	5.51 (2.10)	.077
Effort	5.80 (2.33)	5.59 (2.28)	.102
Emotional Demand	2.66 (1.87)	2.59 (2.11)	.038
Performance Monitoring Demand	5.48 (2.20)	5.72 (2.16)	.161
Global Workload**	4.79 (1.53)	4.40 (1.54)	.444

Note. Values in parentheses represent standard deviations. ** $p < .01$

Ratings of physical demand were higher for manual selection than automatic selection, $t(40) = 5.34$, $p < .001$, $d = 0.837$, and similarly, physical fatigue was higher for manual selection than automatic selection, $t(40) = 2.29$, $p = .027$, $d = 0.358$. However, neither mental demand, $t(40) = 1.92$, $p = .063$, $d = 0.229$, nor mental fatigue, $t(40) = .14$, $p = .891$, $d = 0.022$, were significantly different between the manual and automatic tasks. There was also no significant difference for levels of task-unrelated thoughts between the manual and automatic tasks, $t(40) = 1.28$, $p = .209$, $d = 0.199$. Also significantly higher for the manual task than the automatic task were ratings of concentration, $t(40) = 3.58$, $p = .001$, $d = 0.559$, confidence, $t(40) = 3.74$, $p = .001$, $d = 0.585$, task-related thoughts, $t(40) = 1.28$, $p = .209$, $d = 0.350$, and global workload, $t(40) = 2.84$, $p = .007$, $d = 0.444$. There were no other differences between the manual and automatic tasks, $p > .05$.

Whether task-related thoughts or task-unrelated thoughts were higher for each of the two tasks 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 task, task-related thoughts were significantly higher than task-unrelated thoughts, $t(40) = 4.34$, $p < .001$, $d = 0.678$. Similarly for the automatic task, task-related thoughts were significantly higher than task-unrelated thoughts, $t(40) = 2.47$, $p = .018$, $d = 0.385$.

5.6 Discussion

The current experiment employed a modified version of the SART to investigate the effects that, 1) changing the physical method of responding to targets had and 2) manipulating target distance had on SART performance. This was done with two manipulations: Firstly, to respond to stimuli participants were required either to make no movement except press the mouse button, or make a movement to the location of the stimulus before pressing the button. Secondly, stimuli were located either at a close distance to a central point or farther away. The current experiment suggests that automated response systems may increase the likelihood of friendly fire incidents, and it also provides evidence that is difficult to accommodate within a mind wandering or perceptual decoupling explanation of commission errors in SART-like tasks. The requirement to manually move a crosshair to the stimulus location before initiating a button press response led to slower response times and far fewer commission errors than the automated version where no movement was required prior to the button press. This result suggests that while automated weapons systems may speed up the firing process, they may increase rates of friendly fire accidents.

Considering the two competing perspectives of SART performance can provide insight as to the underlying cause of the differences between the manual and automatic tasks. There were main effects of distance, with stimuli at the far distance yielding both slower response times and fewer commission errors. However, consistent with a response strategy or inhibition perspective, there were also interaction effects between selection and distance. While there were longer response times to far stimuli than to close stimuli for both automatic and manual selection, the difference was much more substantial within the manual task. In terms of commission errors, fewer errors were made to far stimuli than to close stimuli when selection was manual, but no difference was detected between the distances when selection was automatic. Effectively, target distance had much more influence on response times 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 task where response times were slower and commission errors were fewer (manual selection) should have provided more exogenous support of attention, thereby preventing perceptual decoupling and leading to the observations of slower response times 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 any difference in SART performance here could be explained by the physical differences alone. The results yielded no detectable differences for mental demand or fatigue between the manual and automatic tasks, thus evidence consistent with a perceptual decoupling explanation was not found.

Another point where the two different perspectives differ is for task-unrelated thoughts. From the perceptual decoupling perspective, the task where performance was superior should have also yielded fewer task-unrelated thoughts, which would not necessarily be expected from a response strategy perspective. Again, the results failed to support a perceptual decoupling perspective—there were no detectable differences in task-unrelated thoughts between manual and automatic selection. While I believe the methods used here were sound, it should be noted that a lack of detectable differences between measures does not necessarily mean that differences do not exist. In some cases, the measurement used may be insufficient.

Concerning the other self-report findings, confidence was rated higher for the manual task. This may reflect the better withhold performance in this task (much lower commission errors). Concentration and task-related thoughts (from the Stress Scale), and global workload (from the NASA-TLX), were rated higher for the manual task as well. This could reflect the perceived increased effort needed to perform the manual response. In this task, participants did need to perform more operations, including accurately moving and targeting on the box containing the Go stimuli. In addition, these self-reports could, perhaps, provide a rationale for the perceptual decoupling perspective of SART performance. People who perform the original (in this case more akin to our automatic task) SART are aware of their performance and the difficulty inhibiting responses to Go stimuli. This may cause them to make inferences about why their withhold performance was poor. If the strategy selection choice proposed by Peebles and Bothell (2004) is not directly accessible to consciousness, then people may attempt to explain their poor withhold performance with alternative conscious level explanations. Peebles' and Bothell's strategy choice is likely based on simple learning mechanisms and while their strategy choice can be influenced by top-down control (overt strategy choice), the mechanism may itself not be directly accessible to consciousness. An explanation for withhold failures is that participants were not concentrating or focusing on the task as much as they should have been focusing. A participant may therefore conclude they were not concentrating because their performance was relatively poor. The challenge for perceptual decoupling, mindlessness, and mind wandering explanations of SART performance is these self-reports occur after the performance has already occurred. This raises the thorny issues of attempting to understand consciousness and self-reports understanding performance. Regardless, task-unrelated thoughts per se do not differ between the manual and automatic tasks, even though performance is markedly different.

Correlation analyses between commission errors and response times revealed a significant negative correlation, or in other words a speed–accuracy trade-off, for both automatic conditions but also the manual–close condition (albeit a weaker correlation). The link between response speed and response inhibition errors appears to become stronger as physical demands, barriers, or subtasks during SART-like tasks are reduced or eliminated.

The current experiment may have important implications for some applied contexts, such as modern warfare. The possible relation of response inhibition errors in a generic SART situation to the use of firearms has already been demonstrated; in this case with military simulations using human actors representing dismounted soldiers (see Wilson et al., 2013b; 2014; 2015a). 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, 2004). 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. As

Asaro (2012) notes, an operator could essentially be faced with a stream of targets appearing on a screen, for which they will be encouraged to make rapid shoot/no-shoot decisions, despite perhaps having limited prior knowledge about the targets. The nature of a task such as this has clear similarities with the modified SARTs used in the current experiment. The current findings suggest that as weapons systems become more automated, and reductions in physical demands or fewer subtasks (e.g., aiming the weapon) enable operators to thereby respond quicker, the chances of accidental shootings (e.g., friendly fire) will become higher. Indeed, in the current experiment, changing only the mode of response to stimuli from manual to automatic had the effect of increasing commission errors (accidental responding) from 3% to 40%. While the nature of SART-like situations (high Go, low No-Go tasks with high rates of stimuli presentation) contributes to the high commission error rate seen in the current experiment and other similar research too, it still seems that the risk of accidental shooting could become worryingly high in real-life situations, particularly as operators may encounter high rates of targets within short periods of time.

The finding that the far distance reduced commission errors, but that importantly this was only during the manual task and not the automatic task, suggests the response time delay gave participants more time to inhibit a pre-potent motor response routine and thereby stop themselves from making commission errors more often. This contrasts with a perceptual decoupling explanation, wherein the reduction in commission errors would be attributed to the manual response re-engaging participants, or preventing them from becoming perceptually disengaged in the first place. The perceptual decoupling perspective does not account for the difference in commission errors that the small change in distance yielded however. Further supporting the idea that the increased distance gave participants more time to inhibit pre-potent motor responses is the finding that, within the manual task, 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 around 70% of No-Go trials in the manual task, participants actually physically moved the cursor into a box containing a No-Go stimulus, but most of the time they were able to prevent themselves from carrying out the final step of making a response—clicking the mouse. This indicates that the pre-potent motor response routine developed not only in the automatic task but the manual task too, however in the manual task it was *manageable*, e.g. it often did not lead to commission errors. Furthermore this shows that participants respond before identifying the stimulus, or at least before determining whether it is a Go or No-Go stimulus. This reduction in commission errors found in the manual task is consistent with findings elsewhere (Head & Helton 2013, 2014).

The subjective reports, when considered alongside the performance measures, provide further support for a response strategy and inhibition explanation of commission errors and response times rather than to a perceptual decoupling explanation. The results suggest that the reduced numbers of commission errors in the manual task were a result of physical and motor factors, as opposed to mental or perceptual factors.

The lack of any difference in task-unrelated thoughts between the two different methods of response further implies that the much higher commission error rate for the automatic task was not due to participants disengaging their attention from the task per se.

However, differences between several items might challenge a response strategy interpretation and could appear to lend support to a perceptual decoupling explanation. Concentration and task-related thoughts were rated as being higher in the manual task than the automatic task. It is possible that this could partly reflect the increased physical demand of the manual task. Indeed, the finding that global workload—which includes both mental demand and physical demand among other subscale items—was higher for the manual task is likely mostly due to the substantial difference in physical demand between the two tasks. Also, the fact that ratings of confidence were lower for the automatic task could reflect that participants were aware of the difficulty they had in inhibiting responses to No-Go stimuli (evidenced by the high commission error rate). One limitation of the subjective measures employed was that it was only possible to examine the effect that response mode had and impossible to parse out the effect that distance itself had, because selection varied from task to task whereas distance varied from trial to trial (within-task).

The finding within the manual selection task, that more omission errors were made to Go stimuli in the far-distance boxes than to close-distance boxes, may be due to participants not having enough time to move the crosshair the greater distance and make their response on some trials. Nevertheless, overall omission errors in the manual condition were very low (between 0 and 2%) and the mean response time was well below the 1,000 ms cut-off. Furthermore, there was no significant difference between the automatic and manual condition. These observations suggest that participants did have adequate time to make responses in the manual condition.

The significant negative correlations between response times and commission errors (speed–accuracy trade-off) for both of the automatic selection conditions are consistent with typical findings in SART-like tasks (Helton et al., 2005; Helton et al., 2009b; Ishimatsu et al., 2016; Wilson et al., 2015b). 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. Head and Helton (2013) also observed this and a similar explanation to theirs is offered here, namely that participants are likely to have become skilled enough at making responses to close boxes in the manual task, that they were susceptible to speed-induced errors, just as they were in the automatic selection task (though to a much lesser degree in the manual task). The manual–far trials, where stimuli were in far boxes within the manual task, as predicted, did not lead to a speed–accuracy trade-off.

These trials also yielded the slowest response times and, as expected, had the lowest rate of commission errors. Conversely, the condition with the strongest correlation was automatic–close which had the shortest response times and the highest errors of commission rate. It appears that as response times shorten, the association between response times and commission errors becomes stronger.

In terms of future research, if tasks similar to the one employed here are used it may be useful to explore the effect that distance itself has on subjective thought measures, something which was not possible here.

In the current experiment, implementing a manual response selection task led to slower response times, 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. This was not seen in the automatic selection task 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.

SART-like tasks may be a useful tool for understanding the impact that automated weapons systems may have on shoot/no-shoot decisions. The current findings suggest that automating processes that originally required physical input from human operators can lead to failures of response inhibition (e.g., commission errors). Increasing the automation that weapons systems offer may lead to an increased rate of friendly fire accidents. More broadly, in tasks or situations where failures of response inhibition may occur, if an operator's or user's responding can be slowed down they will be better-equipped to prevent these failures from occurring. Introducing an artificial delay appears to provide a degree of protection against response inhibition errors. In terms of the underlying cause of these failures, the findings support a response inhibition or response strategy perspective for commission errors and the trade-off between response speed and commission errors, as opposed to a perceptual decoupling perspective. People need time to inhibit a pre-potent motor response when it is not needed.

5.7 Summary

Weapons systems with high levels of automation, such as those that remove the need for operators to complete certain subtasks (e.g., detecting targets or aiming the weapon) may increase the likelihood of friendly fire. Shortening the physical movement required by the human operator to aim and fire the weapon, or removing it altogether, will likely cause weapons operators to have more difficulty withholding fire on the occasions when they are required to. The implications hold for applied contexts in general, where system operators may be interacting with increasingly automated systems. If the physical movements required of operators are shortened in some way—e.g., by reducing the magnitude of hand movements and thus decreasing the time required to execute the movement (as in the current experiment)—on the occasions when the response must be withheld, operators will have less time available within which to inhibit the pre-potent motor response routine and prevent making an action slip or response inhibition error.

While automated systems may offer advantages, such as increased speed of operations and reduced physical workload for operators, the increased potential for response inhibition errors must be weighed against these benefits. When the consequences of committing a rare action slip or response inhibition error are not worth the benefit gained from the increase in response speed, slowing responses by extending the physical response movement, or enforcing additional actions akin to the "Are you sure?" prompt commonly used in computing, may be an effective intervention. In other circumstances though, when the consequences of a reduction in speed could be more problematic than the consequences of rarely-occurring action slips, this may not be an appropriate intervention. Dismounted combat, where there is a risk of being shot by a faster-firing enemy combatant, could be an example of this.

The current chapter also provides more evidence for a response strategy or response inhibition explanation of SART performance, as opposed to a perceptual decoupling perspective. The improved performance resulting from manually acquiring stimuli, as opposed to stimuli being automatically acquired, appeared to be caused by physical differences alone and enhanced response inhibition, rather than a reduction in perceptual decoupling.

Another question concerns the impact that stress or anxiety may have on performance in SART-like situations. This is important to investigate because firstly, it is currently not clear whether anxiety enhances or impedes response inhibition processes. Secondly, real-world contexts which share important characteristics with SART situations—such as armed combat—can be particularly stressful and anxiety-inducing. Therefore it is imperative that the interaction between stress and response inhibition is understood.

One way to explore the effects of stress and anxiety is to incorporate stimuli into the SART context that are known to induce anxiety or fear. The following Chapter reports an experiment where anxiety-provoking picture stimuli are used as Go and No-Go stimuli in a modified SART.

6 Exploring the Impact of Anxiety on Response Inhibition

6.1 Rationale

Anxiety is a common emotional response experienced during battle (Helmus & Glen, 2005; Meyerhoff et al., 2000; Moore et al., 2012) and many other real-world contexts (see Jones & Hardy, 1990; Prince, Bowers, & Salas, 1994; Spettell & Libert, 1986). Its possible contribution to friendly fire accidents has been noted by authors (Shrader, 1992; Steinweg, 1995). Whilst engaged in actual combat, people will experience vastly different emotions from any that arise from participation in the experiments described in the previous chapters. It is crucial to understand whether response inhibition performance is any different when a person is stressed or experiencing anxiety, as this may impact upon how generalizable the findings in this body of work are to real-life situations.

Previous research suggests that friendly fire errors may be more likely when firearm operators are placed under stress (Patton, 2014), although high Go, low No-Go proportions were not investigated. Therefore, friendly fire errors in Patton's experiment may have been due to factors other than response inhibition (e.g., target misidentification mistakes). Response inhibition may actually be improved by stress. Fewer commission errors have been found when task-irrelevant electric shocks are administered during a SART (Robinson et al., 2013). Perhaps surprisingly, given the strong evidence for speed–accuracy trade-off in SART-like situations, the reduction in commission errors occurred with no detectable increase in response times. In the current Chapter's experiment anxiety was induced in participants by incorporating pictures of anxiety provoking Go or No-Go stimuli in a modified SART.

Additionally, to compare the two perspectives of SART performance in this experiment, self-reported measures of task-related and task-unrelated thoughts were taken alongside the performance measures. The perceptual decoupling perspective would posit that lower task-related thoughts and higher task-unrelated thoughts should be associated with poorer SART performance. Conversely, from a response strategy or response inhibition perspective, task-unrelated thoughts should not be associated with performance. Task-related thoughts may have a relationship with performance, as shown previously (see Chapter 4), however if anything, *more* task-related thoughts should be associated with increased commission errors.

6.2 Abstract[5]

Anxiety can have positive effects on some aspects of cognition and negative effects on others. The current study investigated whether task-relevant anxiety could improve people's ability to withhold responses in a response inhibition task. Sixty-seven university students completed a modified and an unmodified version of the SART and provided subjective measures of arousal and thoughts. Anxiety appeared to improve participants' ability to withhold responses. Further, participants' performance was consistent with a motor response inhibition perspective rather than a mind wandering perspective of SART commission error performance. Errors of commission were associated with response times (speed–accuracy trade-off) as opposed to task-unrelated thoughts. Task-related thoughts were associated with the speed–accuracy trade-off. Conversely task-unrelated thoughts showed an association with errors of omission, suggesting this SART metric could be an indicator of sustained attention. Further investigation of the role of thoughts in the SART is warranted.

6.3 Introduction

Unravelling the relationship between subjective states, especially those which are consciously reportable, and performance may help resolve the role consciousness plays in human behaviour. Matthews et al. write (2002, p. 316), "a subjective state may be defined as a relatively transient mental quality permeating conscious awareness whose representation is distributed across a variety of mental processes or structures, and which has the potential to generalize across activities and contexts." Matthews (2001) proposes a state-mediation model in which environmental conditions and tasks affect internal states which then influence information-processing. Research has explored the performance correlates of conscious states.

For example, anxiety and arousal states affect cognitive performance. Often anxiety has negative consequences, such as being detrimental to working memory (Matthews & Campbell, 1998) and test anxiety has been found to be detrimental to retrieval from long term memory (Kanfer & Ackerman, 1996; Kanfer & Stevenson, 1985). In military operations, stress is thought to contribute heavily to errors in shooting judgement and friendly fire (Shrader, 1992; Steinweg, 1995). Energetic arousal, however, is positively correlated with perceptual sensitivity on high-event target detection tasks and visual search tasks (Funke, Matthews, Warm, & Emo, 2007; Helton, Shaw, Warm, Matthews, & Hancock, 2008; Helton & Warm, 2008; Matthews & Davies, 1998a; Matthews & Davies, 1998b; Matthews, Davies, & Lees,

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1990). Humphreys and Revelle (1984) suggested arousal increases the availability of resources for sustained information-processing. There are situations where experiencing anxiety may also have positive effects on a person's cognition. In a recent study, Robinson, Krimsky, and Grillon (2013) showed that the threat of a painful electric shock increased participants' ability to withhold responses in a response inhibition task. In their experiment anxiety was induced externally to the task itself by the threat of electric shock. Whether or not task-*relevant* anxiety can similarly produce advantageous effects remains to be seen.

In the current study, participants completed a Go/No-Go response task as used by Robinson and colleagues (2013). This time however, the stimuli intended to induce anxiety was incorporated into the task itself, and thus task-relevant anxiety rather than task-irrelevant anxiety was examined. The Go/No-Go response task used was the SART (Roberston et al., 1997). In the current experiment, pictures of spiders judged to be negative and arousing in nature were used, thus incorporating the anxiety-inducing stimuli into the task itself.

SART-like tasks are characterised by a speed–accuracy trade-off, where faster response times are associated with more errors of commission (Helton, 2009; Helton et al., 2009a; Helton et al., 2011b; Ishimatsu et al., 2016; Peebles & Bothell, 2004). While recognized as requiring response inhibition, there has been a debate regarding what the SART actually measures. One perspective is that errors of commission are primarily the result of absentmindedness caused by mind wandering (Smallwood et al., 2004). This theory posits that participants become bored with the monotonous nature of the SART and thus their attention drifts from the task, which is manifested as an increase in task-unrelated thoughts. From this perspective SART commission errors are indicators of perceptual decoupling. Another perspective is that failures to withhold to the rarely occurring targets reflect a break down in the ability to inhibit high strength responses rather than due to perceptual errors per se. The repetitive nature of responding in the SART leads to the development of a pre-potent ballistic motor program, which is difficult to inhibit when necessary (i.e., occurrence of a target; Head & Helton, 2014; Helton et al., 2010). Even when the participant is fully perceptually coupled errors of commission can occur due to motor decoupling resulting from a strategic shift towards speed of response, not perceptual decoupling per se (Head & Helton, 2013). Therefore an additional research goal was to examine how the inclusion of spider picture stimuli affected reports of task-related and task-unrelated thoughts during the SART. Thus, along with performance on the SART participants' subjective arousal levels, both energetic and tense, and both task-related and task-unrelated thoughts were measured with four subscales from the DSSQ (Matthews et al., 1999; Matthews et al., 2002).

It was expected that participants would perform better when exposed to spider pictures in the SART, and also report higher levels of anxiety, showing that task-relevant anxiety improves response inhibition.

Specifically, participants would be said to show 'better' performance if their speed or accuracy was improved in comparison to performance on the neutral digit stimuli SART. According to the mind wandering perspective of the SART, increased commission errors should occur when task-unrelated thoughts are more prevalent. From the motor perspective commission errors will be more frequent when response times are shorter, reflecting speed–accuracy trade-off, rather than task-unrelated thoughts. Indeed, from the motor perspective, self-reported thoughts elicited after the SART likely reflect awareness of task performance and may even be influenced by performance itself (performance appraisal). McAvinue et al. (2005) observed that people were aware of their SART commission errors 99.1% of the time. People are fully aware of their performance on the task. It was predicted that a speed–accuracy trade-off will be apparent, that is, participants who overall respond faster should make more errors of commission, and vice versa.

6.4 Method

6.4.1 Participants

Sixty-seven (39 females, 28 males) undergraduate students from the University of Canterbury in Christchurch, New Zealand, participated in this study. They ranged in age between 17 and 42 years (M = 21.7 years, SD = 5.0). All participants had normal or corrected-to-normal vision.

6.4.2 Materials and Procedure

Participants were tested in individual cubicles. They were given an information sheet and a consent form which they signed. Participants were seated approximately 50 cm in front of a computer screen (377 mm x 303 mm, 75 Hz refresh rate) that was mounted at eye level. Their head movements were not restrained. Wrist watches were removed and mobile phones were switched off. Stimuli presentation and response accuracy and timing were achieved using E-Prime 2.0 software (Schneider et al., 2002).

Two SARTs were used, the original digit SART and a modified SART using pictures of spiders and neutral objects as stimuli. Both required participants to respond by pressing the spacebar to frequently-occurring Go stimuli and withhold responses to rarely occurring No-Go stimuli. Go stimuli occurred with a probability of .89 and No-Go stimuli occurred with a probability of .11. The tasks were each 4.3 min long and consisted of 225 trials. Stimuli were presented for 250 ms, followed immediately by a 900 ms mask comprising of a circle with a diagonal line through it (see Figure 6.1). From the onset of the stimuli participants had a 900 ms window to register a response. The digit SART was an exact replica of that used by Robertson et al. (1997). It required participants to monitor the screen for digit stimuli, withholding responses to the digit 3 (No-Go) and responding to all other digits 1–9 (Go). Digits varied in size and were randomly selected from sizes 48, 72, 94, 100 and 120, and were all displayed in Arial font. There were two versions of the picture SART, both comprising of a mixture of pictures of spiders and pictures of neutral objects or scenes. Both were taken from the Geneva Affective Picture Database (GAPED; Dan-Glauser & Scherer, 2011). Examples of the picture stimuli can be seen in Figure 6.2. In one version the No-Go stimuli were spider pictures with neutral pictures serving as Go stimuli. Picture roles were reversed in the other version.

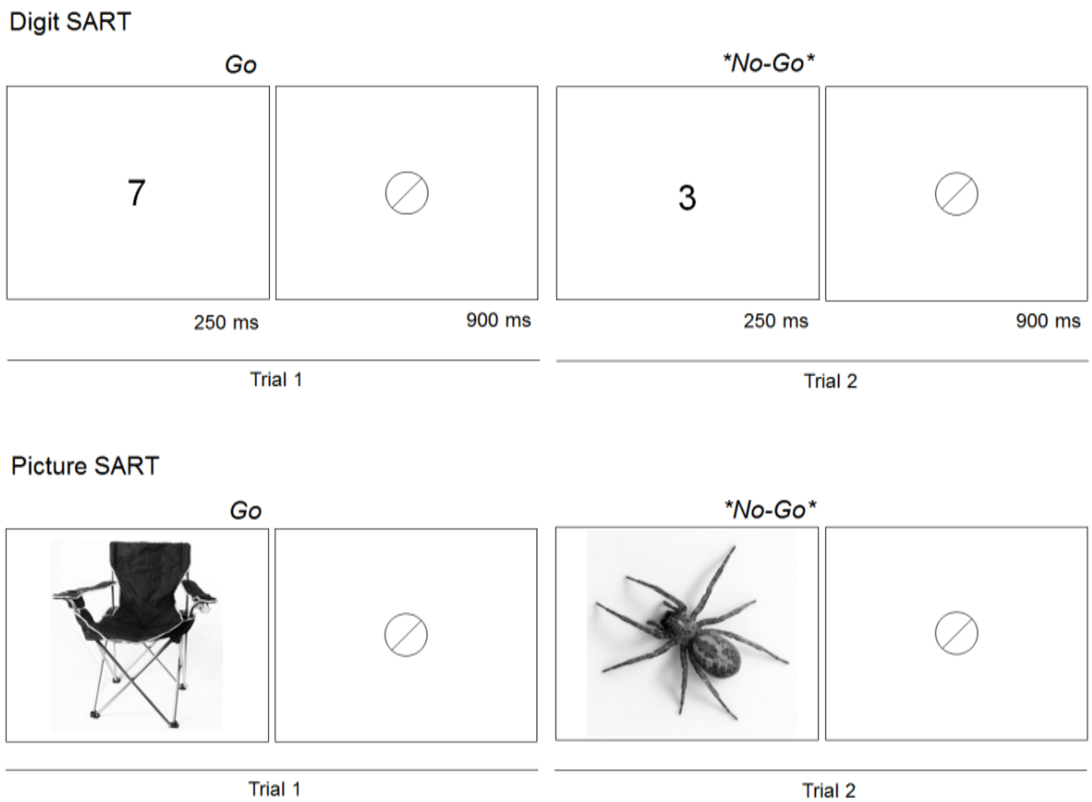

Figure 6.1. Task schematic showing examples of two trials for the digit SART (top) and picture SART (below).

Four subscales from the DSSQ (Matthews et al., 1999) were used to gauge energetic arousal, tense arousal, task-related thoughts, and task-unrelated thoughts. Two additional questions were also asked, the first being “Are you afraid of spiders?” and the second being “How much do you dislike spiders?”. Participants answered this using a 5-pt Likert scale. All participants completed both the digit SART and one of the two picture SARTs with task order being counterbalanced. Subjects were randomly assigned in equal numbers to the two picture versions of the task. Participants completed the four DSSQ subscales and the two additional spider questions on four occasions, before and after each experimental task.

Figure 6.2. Examples of neutral (above) and spider (below) picture stimuli. The picture stimuli can be found at http://www.affective-sciences.org/researchmaterial.

6.5 Results

6.5.1 Behavioural measures

For each subject for each task, picture and digit, the proportion of commission errors, proportion of omission errors, and the mean correct Go-response reaction times were calculated. These data are presented in Table 6.1. Because the participant had only 900 ms in which to respond, the response times are essentially trimmed. For each performance metric a 2 (SART: picture vs. digit) by 2 (spider Go vs. spider No-Go) mixed ANOVA was performed. Participants made significantly fewer errors of commission in the picture SART than in the digit SART, $F(1, 65) = 15.41$, $p < .001$, $\eta_p^2 = .19$. No other results were statistically significant, $p > .05$.

Table 6.1. Behavioural measures between conditions: means and standard deviations.

	Digit	Picture
Errors of commission	.46 (.22)	.37 (.18)
Errors of omission	.01 (.02)	.01 (.01)
Response time (ms)	333.1 (73.8)	321.4 (45.7)

6.5.2 Subjective measures

For each participant their pre-task, post-digit SART, and post-picture SART mean response for each DSSQ scale was calculated: energetic arousal, tense arousal, task-related thoughts, and task-unrelated thoughts. These data are present in Table 6.2. For each DSSQ scale a 3 (time: pre-task, post-digit SART, and post-picture SART) by 2 (spider Go vs. spider No-Go) mixed analysis of variance was performed. Participants whose Go stimuli were spiders reported higher tense arousal (M = 2.58, SD = 0.46) than participants whose Go stimuli were neutral pictures (M = 2.43, SD = 0.35), $F(1, 65) = 4.65$, $p = .035$, $\eta_p^2 = .07$. In addition there was a significant main effect of time for tense arousal, $F(2, 130) = 4.50$, $p = .013$, $\eta_p^2 = .07$. This main effect was followed up with paired t-tests, and the only significant difference was between pre-task tense arousal and post-digit SART tense arousal, $t(67) = 2.75$, $p = .008$. The interaction between time and tense arousal was not statistically significant, $p > .05$. For energetic arousal there were no significant findings, $p > .05$. For task-related thoughts there was a significant main effect for time, $F(2, 130) = 24.16$, $p < .001$, $\eta_p^2 = .27$. This main effect was followed up with paired t-tests, and both post-digit SART, $t(66) = 5.59$, $p < .001$, and post-picture SART, $t(66) = 5.09$, $p < .001$, participants reported more task-related thoughts than at pre-task baseline. For post-task task-related thoughts, post-digit SART and post-picture SART did not differ statistically, $p > .05$. For task-unrelated thoughts there was a significant main effect for time, $F(2, 130) = 23.82$, $p < .001$, $\eta_p^2 = .27$. This main effect was followed up with paired t-tests, and both post-number SART, $t(66) = 6.03$, $p < .001$, and post-picture SART, $t(66) = 4.60$, $p < .001$, participants reported fewer task-unrelated thoughts than at pre-task baseline. For post-task task-unrelated thoughts, post-digit SART and post-picture SART did not differ statistically, $p > .05$. Paired samples t-tests were used to detect any differences between measures of both fear and dislike for spiders after the digit SART versus the picture SART. Ratings of fear for spiders were significantly higher after participants completed the picture task (M = 2.45, SD = 1.23), than after the digit task (M = 2.30, SD = 1.26), $t(66) = 3.06$, $p = .003$. Post-task ratings of dislike for spiders did not differ statistically between the digit SART and the picture SART, $p > .05$. As indicated by the overall scores for the anxiety-related measures, in general participants had low-moderate levels of anxiety before the task and these were slightly increased post-task.

Table 6.2. DSSQ means and standard deviations.

	Pre-task (baseline)	Post-digit	Post-picture
Energetic arousal	2.55 (.30)	2.54 (.41)	2.56 (.35)
Tense arousal	2.57 (.36)	2.42 (.42)	2.51 (.41)
Task-related thoughts	2.29 (.80)	2.93 (.99)	2.82 (.91)
Task-unrelated thoughts	1.91 (.67)	1.43 (.53)	1.49 (.53)

6.5.3 Relationships between behavioural and subjective measures.

For both the digit SART and the picture SART the relationships between the DSSQ self-report measures at pre-task baseline and post-task with performance were examined. The simple correlation coefficients are presented in Table 6.3 with the results for the digit SART above the main diagonal and the results for the picture SART below the main diagonal.

Table 6.3. Correlations (*r*) between performance metrics and self-reported measures (picture SART below the main diagonal; digit SART above).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Response time		-.656**	.097	.403**	.022	-.034	.014	-.021	.099	-.263*	.302*	-.194	-.073	-.229	-.052
2	Commission errors	-.672**		.130	-.230	.147	.038	.023	-.141	.055	.301*	-.069	.067	.035	.092	.104
3	Omission errors	-.067	.125		.186	.337**	.118	.272*	.049	.245*	-.002	.258*	.054	.000	-.100	-.022
4	Energetic arousal - Pre	.226	-.081	.283*		.181	-.016	.167	.191	.240	-.089	.338**	-.141	.088	-.100	.099
5	Tense arousal - Pre	-.020	-.081	.151	.181		.185	.296*	.120	.352**	.195	.313**	.042	.158	-.004	.028
6	Task-related thoughts - Pre	-.028	-.035	.140	-.016	.185		.391**	.104	.203	.464**	.258*	.180	.223	.272*	.200
7	Task-unrelated thoughts - Pre	.190	-.124	.277*	.167	.296*	.391**		.186	.202	.076	.443**	.037	.009	.073	-.058
8	Energetic arousal - Post	-.082	-.046	.192	.409**	.311*	.093	.322**		.416**	.292*	.205	.118	.104	.116	.182
9	Tense arousal - Post	-.057	-.040	.202	.337**	.513**	.250*	.344**	.481**		.260*	.195	-.049	.060	.079	.118
10	Task-related thoughts - Post	-.252*	.249*	.121	-.049	.110	.504**	.222	.184	.299*		.172	.163	.230	.269*	.179
11	Task-unrelated thoughts - Post	.119	.079	.095	.249*	.106	.248*	.242*	.080	.288*	.208		.152	.117	.021	.069
12	Spider fear - Pre	-.200	.005	.026	-.141	.042	.180	.037	.009	.113	.147	.137		.731**	.832**	.636**
13	Spider dislike - Pre	-.110	-.053	.024	.088	.158	.223	.009	.105	.168	.152	.037	.731**		.720**	.876**
14	Spider fear - Post	-.231	-.004	.024	-.019	-.006	.256*	.068	.014	.164	.183	.092	.824**	.756**		.692**
15	Spider dislike - Post	-.179	.016	-.029	.076	.090	.178	-.064	.078	.216	.190	.030	.636**	.886**	.758**	

* $p < .05$

** $p < .01$

Of particular interest is the relationship task-related thoughts appear to share with errors of commission and response time. For both the picture and the digit SART, post-task task-related thoughts correlated positively with errors of commission and negatively with response time. Thus participants who reported more post-task task-related thoughts were faster to respond and made more commission errors. To investigate this possible mediating role of response time with task-related thoughts and errors of commission hierarchical regression analyses as outlined by Baron and Kenny (1986) were used.

For the digit SART, firstly a model was tested to determine whether post-task task-related thoughts predicted response time. This model was significant, $F(1, 65) = 4.84$, $p = .031$, $R^2 = .07$, $\beta = -.26$, $t = -2.20$. Following this a model was tested to see whether post-task task-related thoughts predicted errors of commission. The model was significant, $F(1, 65) = 6.49$, $p = .013$, $R^2 = .09$, $\beta = .30$, $t = 2.55$. The mediation test was then performed by entering response time and post-task related thoughts into the predictive model, to test whether post-task related thoughts was still a significant predictor of commission errors when response time was included in the model. The total model was significant, $F(2, 64) = 25.98$, p

$< .001$, $R^2 = .45$. Response time was significant, $\beta = -.62$, $t = -6.44$, $p < .001$, however post-task related thoughts was not, $\beta = .14$, $t = 1.43$, $p = .156$.

For the picture SART, firstly a model was tested to determine whether post-task related thoughts predicted response time. This model was significant, $F(1, 65) = 4.41$, $p = .040$, $R^2 = .06$, $\beta = -.25$, $t = -2.10$. Following this a model was tested to see whether post-task related thoughts predicted errors of commission. The model was significant, $F(1, 65) = 4.29$, $p = .042$, $R^2 = .06$, $\beta = .25$, $t = 2.07$. The mediation test was then performed by entering response time and post-task related thoughts into the predictive model, to test whether post-task related thoughts was still a significant predictor of commission errors when response time was included in the model. The total model was significant, $F(2, 64) = 27.04$, $p < .001$, $R^2 = .46$. Response time was significant, $\beta = -.65$, $t = -6.84$, $p < .001$, however post-task related thoughts was not, $\beta = .09$, $t = .89$, $p = .375$.

These results suggest that response speed was the main contributor to commission errors in the SARTs, rather than task-related thoughts per se. Response speed appeared to mediate the relationship between task-related thoughts and errors of commission. Essentially, task-related thoughts were associated with the speed–accuracy trade-off.

6.6 Discussion

Participants made fewer errors of commission in the picture SART than the digit SART. There was no significant difference in response times between the two tasks. Participants who had spider stimuli as their Go stimuli in the picture task reported higher levels of tense arousal than those who had spiders as No-Go stimuli. However there were no other significant differences between those with spiders as Go versus No-Go stimuli. There were several significant changes seen over time. Reports of task-related thoughts were significantly higher post-task than at baseline before commencing the tasks. Reports of task-unrelated thoughts and tense arousal were both significantly lower post-task than at baseline. Reported fear for spiders following the picture SART was significantly higher than after the digit SART. Correlation analyses revealed a strong significant relationship between response times and errors of commission for both of the traditional and picture SARTs, as expected. Post-task task-related thoughts appeared to be associated with both response times and errors of commission for both tasks. Subsequent hierarchical regression analyses showed that the effect of task related thoughts on commission errors was mediated by response time, in fact ratings of task related thoughts made no detectable contribution to predicting commission errors over and above that shared with response time. Pre-task task-unrelated thoughts seemed to be more closely linked to errors of omission for both tasks.

The finding that participants were more accurate in the picture SART than the digit SART supports the hypothesis that task-relevant anxiety can improve response inhibition. While the greater spider-related anxiety was not clearly evident in the questionnaire results, participants were more fearful of spiders after the picture SART, suggesting this task may have exacerbated any pre-existing spider related fear. Also, in the picture SART tense arousal was higher in the condition that contained the greater proportion of spider pictures. If participants indeed found the picture SART to be more arousing than the digit SART, this could explain why they made fewer errors of commission, at no cost to response time. This is in line with Robinson and colleagues' (2013) whose findings suggest that the threat of shock improved people's ability to withhold habitual pre-potent responses in SART-like situations.

If anxiety can indeed improve response inhibition, this has implications for critical situations where people may experience acute anxiety or stress. For instance, a soldier engaged in an intense battle at close quarters may have an improved ability to withhold fire and thus have a reduced likelihood of committing a friendly fire accident. Despite acute combat stress being thought to impair many functions in a soldier, its positive effects have been documented too, such as in "energizing" the soldier and improving reflexive speed (Moore et al., 2012). Perhaps improved response inhibition is another positive effect that acute anxiety can offer. Another question concerns whether effects are contingent upon the specific nature of the stress being experienced. For instance, chronic stress may not induce the same effects as acute stress (e.g., a reaction to a specific anxiety-inducing stimulus). If there are differences, the current findings are likely to be more relevant to incidents where personnel are exposed to anxiety-inducing stimuli and experience acute stress.

One alternative explanation however relates to visual salience, that is, participants found it easier to discriminate between spiders and the neutral pictures, than between the digit 3 and the remaining digits 1–9. If spiders were indeed easier to discriminate this could have been simply due to the characteristic and consistent spider profile, that is, long thin legs extending out from a central body, enabling quicker picture recognition. Increasing the visual salience of stimuli has been shown to decrease errors of commission (Smallwood, 2013). Yet another alternative is that a facilitated discrimination could be due to an inbuilt predator detection mechanism, such as that proposed by Rakinson and Derringer (2008) who found evidence suggesting young infants had an evolutionary-evolved perceptual template of spiders. Presumably it is advantageous for humans to be quick to recognise a potential threat such as a spider. Further support for the idea that spider stimuli may have improved performance through increased ease of discrimination was the observation that response time in the picture task appeared to be faster than that for the digit task. This suggests the picture SART may have offered a *general* SART performance improvement, that is, quicker response times alongside the improved accuracy rates, which would suggest spider detection was superior to digit detection overall. This difference was not statistically significant however. Further examination of this idea is required.

While no performance differences dependent upon whether spiders were targets or distractors in the picture task were detected, participants who had spiders as Go stimuli reported significantly higher tense arousal than participants who had spiders as No-Go stimuli. Perhaps forcing participants to physically respond to spiders induced anxiety, just as repetitively touching spiders could induce anxiety. The sheer volume of spiders in the Spider-Go condition could also have contributed to this (89% spiders in Spider-Go versus 11% spiders in Spider-No-Go). Furthermore, while tense arousal reduced from pre-task to post-task for the digit SART, this did not occur in the picture SART.

Task-related thoughts increased from pre-task to post-task for both the picture and digit SART, while task-unrelated thoughts showed the opposite, decreasing from pre-task to post-task for both tasks. Task-related thoughts were closely associated with errors of commission and response time, the two metrics central to the SART's speed–accuracy trade-off. As expected, there was a marked speed–accuracy trade-off between response time and errors of commission for both tasks. Post-task related thoughts significantly correlated with both of these measures. Participants who had faster response times reported more post-task related thoughts, and similarly those who made more commission errors reported more post-task task-related thoughts. Hierarchical regression analyses revealed a mediating relationship between these variables, where the effect of task-related thoughts on commission errors was dependent upon response time or vice versa. Two explanations could be offered regarding these findings. First, perhaps participants who experienced an increase in task-related thoughts during the task sped up their response times, leading to a subsequent increase in errors of commission. Alternatively, participants adopting a faster response strategy where they in-turn made more commission errors may have then experienced an increase in task-related thoughts.

Task-unrelated thoughts on the other hand shared a relationship with errors of omission. Greater task-unrelated thoughts before the task were associated with more omission errors during the task. For the digit SART, post-task task-unrelated thoughts were also associated with omission errors. While the use of the commission error metric for addressing sustained attention is probably not appropriate, as it likely reflects failures of response inhibition, not perceptual awareness per se, perhaps the SART omission error metric can be used as an indicator of sustained attention. Task-unrelated thoughts are associated with total omission errors on low Go vigilance tasks as well (Helton & Warm, 2008). In addition, errors of omission on the SART were previously found to be elevated after exposure to a natural disaster than prior to the disaster, perhaps indicative of the sensitivity of errors of omission to disaster induced cognitive disruption (Head & Helton, 2012).

Future research could explore the extent to which the improvements in commission errors noted in this experiment were actually due to increased anxiety versus improved perceptual salience. In addition, research resolving the causal direction between self-reports of task-related and task-unrelated thoughts and performance in the SART would be useful. Claims that SART errors of commission are indicators of mind wandering in particular warrant further examination. In this experiment errors of commission and global reports of task-unrelated thoughts were not associated. This has also been the case in other studies using global assessments of task-unrelated thoughts (Head & Helton, 2014) as well as in Chapter 4. Researchers using more immediate thought probes have found an association between commission errors and reports of off-task thoughts (Smallwood et al., 2004), however, as McAvinue et al. (2005) observed people are aware of their SART commission errors 99.1% of the time. If participants are probed immediately after a commission error in regards to whether they were task-focused or thinking about something else, their performance itself may influence their thought report (e.g., if a person makes an error and then is asked immediately what they were thinking about, they may conclude that because they made an error they must have been thinking about something other than the task). Integrating additional measures of conscious awareness should allow researchers to successfully assess these different possibilities.

6.7 Summary

Pictures of anxiety inducing spiders were used in a modified SART as Go or No-Go stimuli, as a form of task-relevant anxiety. Subjects made fewer commission errors in the modified spider-picture SARTs than a digit SART. This is consistent with Robinson et al.’s (2013) finding that participants exposed to the threat of electric shock made fewer commission errors. In a combat context, this might suggest that riflemen may actually benefit from acute anxiety, by being better able to withhold their fire when they confront allied soldiers or non-combatants. However, the reduced commission errors in the picture SART may not arise from the anxiety-inducing characteristics of the spider stimuli but rather because spider pictures are easier to distinguish from neutral pictures than the digit 3 is from the remaining digits. Further exploration of the impact of anxiety-provoking stimuli on SART-like performance and response inhibition was required. Chapter 7 examines this more closely.

In terms of the relationship between subjective measures and performance, higher task-related thoughts were associated with faster response times and increased commission errors. Task-unrelated thoughts however shared no relationship with response times or commission errors in either task. Furthermore, task-related thoughts increased significantly from pre-task to post-task while task-unrelated thoughts showed the opposite. These findings are in direct contrast to a perceptual decoupling perspective.

7 The Effect of Anxiety-provoking Stimuli and Warning Cues in a Modified SART

7.1 Rationale

The main purpose of Chapter 7 is to further explore the effects of anxiety on response inhibition after Chapter 6 raised additional questions worth exploring. In the current experiment, pictures that were rated high in negative valence and arousal are incorporated into a modified SART. A comparative “neutral picture” control is also used. In addition to picture stimuli being either negative or neutral in valence, these stimuli can be either predictive or non-predictive of a forthcoming No-Go stimulus. That is, predictive stimuli occurred immediately before the onset of No-Go stimuli in the task (effectively serving as a warning cue) whereas non-predictive stimuli occurred randomly before Go or No-Go stimuli. Manipulating predictability enabled the effects of task-relevant anxiety (predictive condition) versus task-irrelevant anxiety (non-predictive condition) to be isolated.

Understanding how acute anxiety affects response inhibition has important implications for real-world contexts such as modern warfare. In combat, anxiety is thought to impair decision-making, but have positive effects in other areas such as reflexive speed and energy levels (Moore et al., 2012). Less is known about the effects of acute anxiety on friendly fire though. The impact of anxiety on response inhibition can provide insight into whether soldiers may be more or less likely to commit friendly fire accidents, when they are involved in fast-paced engagements where response inhibition appears to play a role. This knowledge can inform the design of training procedures, personnel selection, and decision making by military commanders.

This Chapter also explores the idea that predictive warning cues could mitigate response inhibition errors without the typical cost in response speed (also see Finkbeiner et al., 2015; Helton et al., 2011a; 2011b). Chapters 3 through to 5 show the extent to which performance in SART-like situations is dependent upon speed–accuracy trade-offs. Most of the time improvements in response inhibition come at the expense of response speed. In many situations it may be appropriate to encourage or even to enforce (e.g., see Chapter 5) a reduction in response speed, in order to obtain the benefit of increased accuracy. There are certain situations where this may not be practicable however. Close quarters combat presents one such operational context where an improvement in accuracy (e.g., improved ability to withhold fire) may not be feasible given the associated reduction in response speed (e.g., longer time to fire) that comes as a trade-off. One possible method to avoid this trade-off in speed though, could be to use warning cues which predict the nature of forthcoming stimuli. If reliable warnings (predictive condition) improve SART performance but unreliable warnings do not (non-predictive condition) this could be one method for improving response inhibition without trading off response speed in real-world contexts.

7.2 Abstract[6]

The impact of anxiety-provoking stimuli on the SART, and response inhibition more generally, is currently unclear. Participants completed four SARTs embedded with picture stimuli of two levels of emotion (negative or neutral) and two levels of task-relevance (predictive or non-predictive of imminent No-Go stimuli). Negative pictures had a small but detectable adverse effect on performance regardless of their task-relevance. Overall, response times and rates of commission errors were more dependent upon the predictive value of the pictures than their attention-capturing nature (i.e., negative valence). The findings raise doubt over whether anxiety improves response inhibition. This has implications for operational environments where people may experience highly negative stimuli and acute anxiety, such as in small arms combat. During intense close quarters combat, soldiers may experience an impaired ability to withhold responses, elevating the risk of friendly fire accidents. In the current experiment, performance improved considerably when predictive warnings of No-Go stimuli were provided, suggesting that providing information about the imminent appearance of allies and civilians could be one method to mitigate friendly fire errors. The findings also lend support to a response strategy perspective of SART performance, as opposed to a mindlessness or mind wandering explanation.

7.3 Introduction

The SART is a Go/No-Go response task requiring motor inhibition (Robertson et al., 1997). In the SART subjects make repetitive responses to Go stimuli on approximately 90% of trials, but have to withhold responses to rarer No-Go stimuli. The speeded repetitive responding in the SART results in the development of a feed-forward ballistic motor program (Head & Helton, 2013; Robertson et al., 1997). Indeed, commission errors (responses to No-Go stimuli) are more likely in SART-like situations when responses to Go stimuli are faster suggesting a trade-off between the speed of response to Go stimuli and the ability to withhold responding to No-Go stimuli (Helton, 2009). The SART provides a measure of the ability to inhibit pre-potent motor responses.

Robinson and colleagues (2013) in a prior study using the SART demonstrated that the administration of task-irrelevant electric shocks to participants during the SART reduced commission errors without affecting response times to Go stimuli. A number of factors influence SART performance by shifting the

[6] Submitted paper. This chapter is based on: Wilson, K. M., Finkbeiner, K. M., de Joux, N. R., Russell, P. N., & Helton, W. S. (submitted, September 2015). The effect of task-relevant and irrelevant anxiety-provoking stimuli on response inhibition.

participants' emphasis on speed at the cost of accuracy or vice versa (Head & Helton, 2013, 2014; Seli et al., 2012, 2013), but in this case the administration of shocks improved response inhibition with no evidence of a response strategy shift. To further examine this finding, Wilson and colleagues (2015b) developed a modified SART in which pictures of spiders and neutral stimuli served as the Go or No-Go stimuli (both combinations were used). They compared this modified spider picture SART with the original SART in which the Go and No-Go stimuli are the digits 1–9. Since spiders are anxiety provoking stimuli (Gerdes, Uhl, & Alpers, 2009), Wilson and colleagues predicted in line with Robinson et al. (2013) that the spider SART in comparison to the digit SART would result in fewer commission errors but at no cost to response time. This prediction was upheld. However, the authors also proposed that spider and neutral picture stimuli may simply be more readily and quickly discriminated than the digits used in the traditional SART. People may have the ability to detect and recognise spiders extremely quickly (Flykt, 2005; LoBue, 2010), which would facilitate discrimination of Go and No-Go stimuli. Smallwood (2013) found that making the No-Go digit stimuli red versus the Go digit stimuli black improved accuracy at no cost to response time in the digit SART.

The impact of affect provoking stimuli on the SART, or response inhibition more generally, is unclear. In terms of tasks involving fine motor control, exposure to negative picture stimuli has been shown to increase error after short exposure and increase speed following long exposure (Coombes, Janelle, & Duley, 2005). In cognitive tasks, negative emotional stimuli have been found to impair task performance by competing with attentional resources (Helton & Russell, 2011; Ossowski, Malinen, & Helton, 2011). In a task where participants made multiple shoot or no-shoot decisions, similar to the way SART participants make responses to Go and No-Go stimuli, stress induced through the use of a shock belt led to more commission errors (Patton, 2014). Unlike Robinson et al. (2013) shocks in Patton's study increased failures to inhibit responses. However, while the shocks in Robinson et al.'s experiment were task-irrelevant (shocks were not associated with the participants' behaviour), in Patton's study they were task-relevant (dependent upon participants' behaviour).

The role of affect provoking stimuli on response inhibition clearly warrants further exploration. In the current experiment picture stimuli were embedded into modified SARTs in a factorial design combining two levels of emotion (negative vs. neutral pictures) and two levels of task-relevance (predictive or task-relevant vs. non-predictive or task-irrelevant). In our SARTs, the pictures either did predict or did not predict the imminent onset of No-Go stimuli. In one condition, all pictures reliably predicted the occurrence of No-Go stimuli whereas in another condition they occurred randomly, before Go or No-Go stimuli. In addition, the pictures were either rated high for negative valence and arousal or rated neutral for valence and arousal. Participants performed four modified SARTs: predictive–negative, predictive–neutral, non-predictive–negative, and non-predictive–neutral.

The experimental design allows us to determine whether the effect of stimulus valence is moderated by the task-relevance (predictive vs. not predictive). If stimulus valence affects SART performance regardless of the task-relevance of the picture stimuli, a statistically reliable emotion main effect will be found. If the effect of stimulus valence is moderated by task-relevance an emotion x relevance interaction effect will be evident. There is less uncertainty about the effects of task-relevance on commission errors. In previous studies, predictive warning stimuli improved SART performance (Finkbeiner et al., 2015; Helton, Head, & Russell, 2011; Helton et al., 2011a) through reducing commission errors as well as shortening response times. Using warning stimuli may be one method to manage response inhibition errors in a highly time-sensitive context such as a battle space (see Wilson et al., 2015a). This contrasts with many other modifications which can "improve" SART performance, such as making participants respond in time with delayed audible cues (Seli et al., 2013), lengthening the physical movement required to execute responses (Chapter 5), or decreasing the proportion of Go relative to No-Go stimuli (Chapter 4). Often, while these factors may improve commission error performance, they typically do so at the cost of increased response time. In some contexts this could be problematic and even dangerous. On a battlefield, delaying the speed with which a soldier can fire (i.e., in SART terms, their speed of responding to Go stimuli), may reduce their risk of accidentally shooting an ally or a civilian but at the same time it could expose them to a higher risk of being shot by faster-firing enemy combatants. This is one dilemma faced when attempting to manage failures of response inhibition, such as those seen in the SART. Predictive warnings that reliably inform soldiers of whether the entity they are about to confront is a friend or a foe could reduce the rate of friendly fire and crucially it could do so without any concurrent cost in firing speed. In the current experiment, statistically significant main effects of task-relevance—whereby predictive stimuli lead to fewer commission errors and shorter response times—would support the idea that providing soldiers with predictive target warnings could benefit shoot/no-shoot behaviour. Self-report measures were included to verify that that the negative pictures effectively elicited negative emotional reactions. In addition, the inclusion of the self-report measures addresses the ongoing debate in the SART literature as to the underlying cause of commission errors. From an inattention perspective, decreases in self-reported task-related and task-unrelated thoughts (mindlessness) or increases in task-unrelated thoughts (mind wandering) are often taken as evidence of perceptual decoupling.

Alternatively, from a response strategy or response inhibition perspective it is possible to explain the trade-off between the risk of responding to No-Go stimuli and speed of response to Go stimuli without invoking attention, mindlessness, mind wandering or perceptual decoupling at all (e.g., Helton et al., 2009b; Peebles & Bothell, 2004).

Concerning the self-report stress scale, two items that are of particular interest to this debate are the measures of task-related thoughts and task-unrelated thoughts, as these measures are central to the two main competing theories. From an inattention perspective, increased task-unrelated thoughts and/or decreased task-related thoughts should be seen in the condition where SART commission errors are highest, because mind wandering and mindlessness are thought to cause commission errors (Robertson et al., 1997). On the other hand, those advocating a simple response strategy perspective do not necessarily expect high task-unrelated thoughts/low task-related thoughts in the SART with the highest commission errors, because this view does not attribute errors to failures of conscious attention per se. From a response strategy perspective if subjects are sensitive to stimulus contingencies and relative probabilities of Go and No-Go stimuli then task performance should depend much more on the predictive value of warning cues than to the attention-capturing potential of the stimuli or reports of conscious focus.

7.4 Methods

7.4.1 Participants

Forty-two (16 male, 26 female) undergraduate students from the University of Canterbury in Christchurch, New Zealand, participated as part of a course laboratory class requirement. They ranged in age between 17 and 53 years (M = 21.5, SD = 12.3). All participants had normal or corrected-to-normal vision.

7.4.2 Materials

Participants were tested in individual workstation cubicles, and were seated approximately 50 cm in front of Phillips 225B2 LCD computer screens (1680 x 1050 pixels, 60 Hz refresh rate) that were mounted at eye level. Participants' head movements were not restrained. Stimuli presentation, response accuracy and timing were achieved using E-prime 2.0 software (Schneider et al., 2002).

The tasks were modified versions of the SART (Robertson et al., 1997). They required participants to monitor the screen for digit stimuli, responding to frequently-occurring Go stimuli (the digits 1–9, excluding 3) and withholding responses to infrequent No-Go stimuli (the digit 3). Go stimuli occurred with a probability of .89 and No-Go stimuli occurred with a probability of .11. Digits varied in size and were randomly selected from point sizes 48, 72, 94, 100, and 120, and were all displayed in Arial font. Each task consisted of 225 trials. In addition to the digit stimuli, which occurred on every trial, picture stimuli were also incorporated into the SARTs. These were presented on 11% of trials (the same amount as No-Go trials) and their presentation always came immediately before digit stimuli. The picture stimuli were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2001). The IAPS contains picture stimuli rated for both arousal and valence on a 9-point scale. Two sets of picture stimuli (N = 25 for each) were used: a neutral set and a negative set. Pictures selected for the neutral set were rated as being neutral in valence (M = 5.02, SD = 0.13) and low in arousal (M = 3.04, SD

= 0.59), while pictures selected for the negative set were rated as being negative in valence (*M* = 1.79, *SD* = 0.33) and high in arousal (*M* = 6.64, *SD* = 0.53). Two of the tasks contained neutral pictures (e.g., a towel and a satellite) while the other two contained negative pictures (e.g., a mortally injured person and a gun pointing at the participant). Pictures spanned the width and height of the screen. A second manipulation was the predictive nature of the picture stimuli. In the two predictive (task-relevant) tasks, pictures always came before No-Go stimuli, effectively serving as predictors of No-Go stimuli on 100% (25/25) of the No-Go trials. In the two non-predictive tasks (task-irrelevant) the pictures had equal likelihood of occurring before any of the digit stimuli, 1–9.

Participants completed all four tasks (predictive–negative; predictive–neutral; non-predictive–negative; non-predictive–neutral) in a repeated measures design. Half of participants began with a task containing negative pictures and the other half began with a task containing neutral pictures, and similarly for half of participants the predictive task was completed before the non-predictive task. Assignment of subjects to task orders was determined randomly. To prevent potential confusion arising from alternating between predictive and non-predictive picture conditions participants always completed either both predictive tasks or both non-predictive tasks first.

In addition to the modified SARTs, self-report measures were used to assess participants' stress and emotional response to each task. A Stress Scale questionnaire (Blakely, 2014; Sellers, 2013; Sellers et al., 2014) was completed by participants following each task. This consisted of 11 Likert scale items with a scale of 0 ("very low") to 100 ("very high"). These individual items were each based on factors from the DSSQ (Matthews et al., 1999).

7.4.3 Procedure

Participants were given an information sheet and a consent form which they signed. Wrist watches were removed and mobile phones were switched off. Participants were instructed to respond by pressing the spacebar to every digit 1–9 except for the digit 3, and told to emphasise speed and accuracy equally.

Participants firstly completed a practice session to familiarise them with the task requirements. Accuracy feedback was given verbally during the 18 trials which took approximately 40 s to complete. No picture stimuli were included here and it was essentially identical to a typical digit SART. Participants were informed of the predictive nature (either predictive or non-predictive) of each forthcoming task immediately before they commenced it. Subjects were not told whether the pictures would be negative or neutral—they were however told at the beginning of the experiment that each task contained either negative or neutral pictures.

On non-picture trials (89% of trials) a mask consisting of a ring with a diagonal line through it firstly appeared on screen for 450 ms. On picture trials a picture appeared for 250 ms, followed by the mask for

200 ms. Following this for both trial types, a digit stimulus appeared for 250 ms. Finally, the mask was displayed on screen for 750 ms (see Figure 7.1). Responses were recorded up to 1,000 ms following stimulus onset. The onset-to-onset interval was 1,450 ms and each task was approximately 5.4 min in duration. Immediately after each task participants completed the Stress Scale (four times in all). The whole experiment took approximately 30 min to complete.

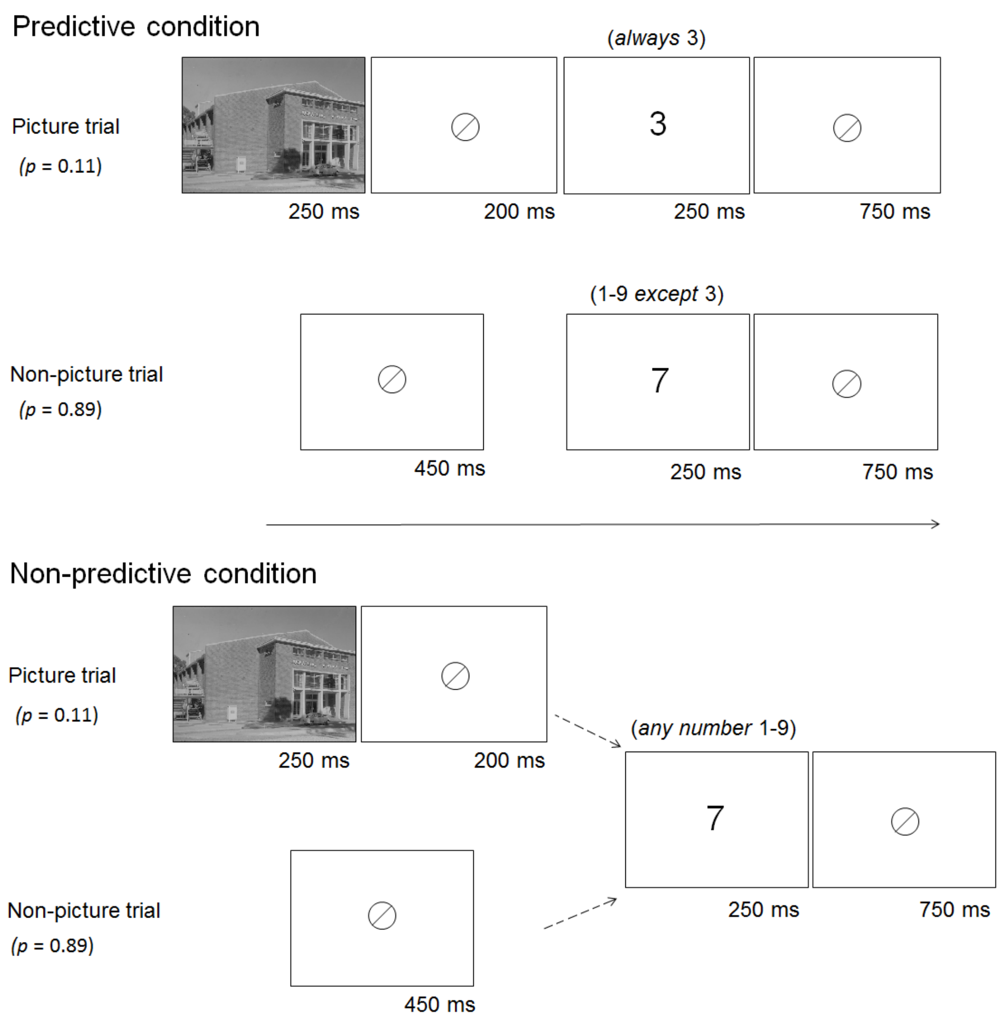

Figure 7.1. Schematics depicting examples of trials for the predictive (top) and non-predictive condition (bottom).

7.5 Results

Results from 2 participants were excluded because their excessive number of commission and omission errors in each task indicated they failed to follow task instructions or engage in the tasks.

7.5.1 Behavioural measures

For each subject in each task, the proportion of commission errors (Figure 7.2), omission errors (Figure 7.3), and the mean correct response times to Go stimuli (Figure 7.4) were calculated.

Separate 2 (emotional valence: negative vs. neutral) x 2 (task-relevance: predictive vs. non-predictive) repeated measures ANOVAs were performed on each of the three performance measures. These were then followed up with paired sample *t*-tests when appropriate.

For errors of commission, there was a significant main effect of task-relevance, $F(1, 39) = 125.23$, $p < .01$, $\eta_p^2 = .76$, with significantly more errors made for the non-predictive condition than the predictive condition. There was also a significant valence main effect, $F(1, 39) = 4.02$, $p = .05$, $\eta_p^2 = .09$, with more commission errors occurring in the negative than the neutral condition. There was no interaction effect, $p > .05$.

For errors of omission, there was a significant main effect of valence, $F(1, 39) = 7.42$, $p = .01$, $\eta_p^2 = .16$, with more omission errors made in the negative condition than the neutral condition. There was no main effect for task-relevance, $p > .05$, however there was a significant interaction effect between valence and task-relevance, $F(1, 39) = 7.93$, $p = .01$, $\eta_p^2 = .17$. A paired *t*-test revealed that there were significantly more errors made in the negative valence than the neutral valence when pictures were non-predictive, $t(39) = 3.27$, $p < .01$, $d = .52$. To determine if this effect was limited to picture trials or non-picture trials within the non-predictive condition, a further paired *t*-test was conducted. This revealed that the effect of increased omission errors was limited to picture trials within the non-predictive condition; there were significantly more errors of omission made on trials containing negative pictures than trials containing neutral pictures, $t(39) = 3.56$, $p < .01$, $d = .56$.

For response time, there was a significant main effect of prediction, $F(1, 39) = 146.80$, $p < .01$, $\eta_p^2 = .79$, with response times to Go stimuli faster in the predictive condition than the non-predictive condition. There was no main effect of valence and no interaction effect, $p > .05$.

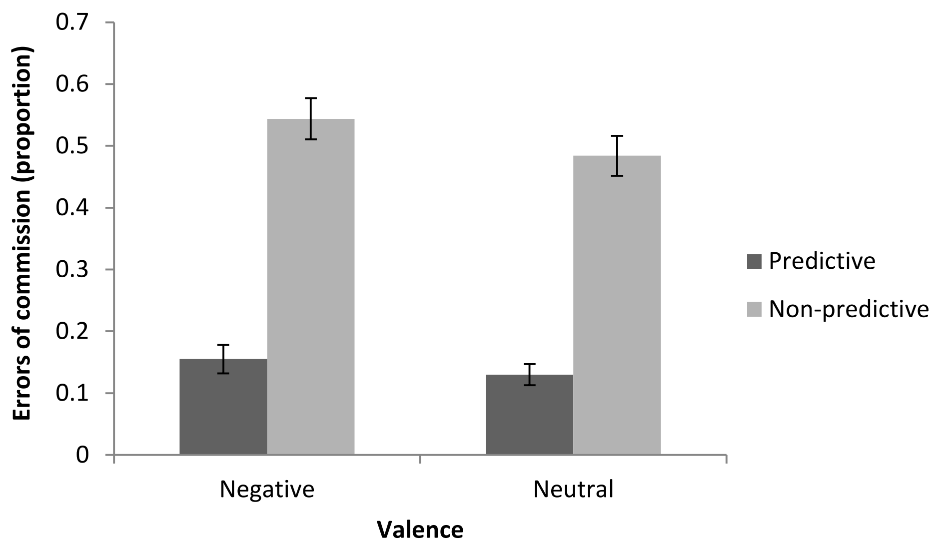

Figure 7.2. Mean proportion of errors of commission in the four tasks. Error bars are standard errors of the mean.

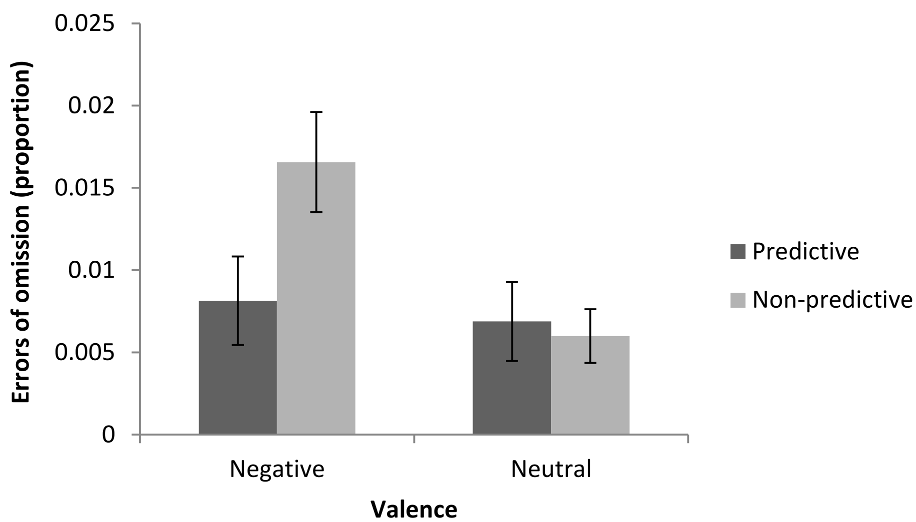

Figure 7.3. Mean proportion of errors of omission in the four tasks. Error bars are standard errors of the mean.

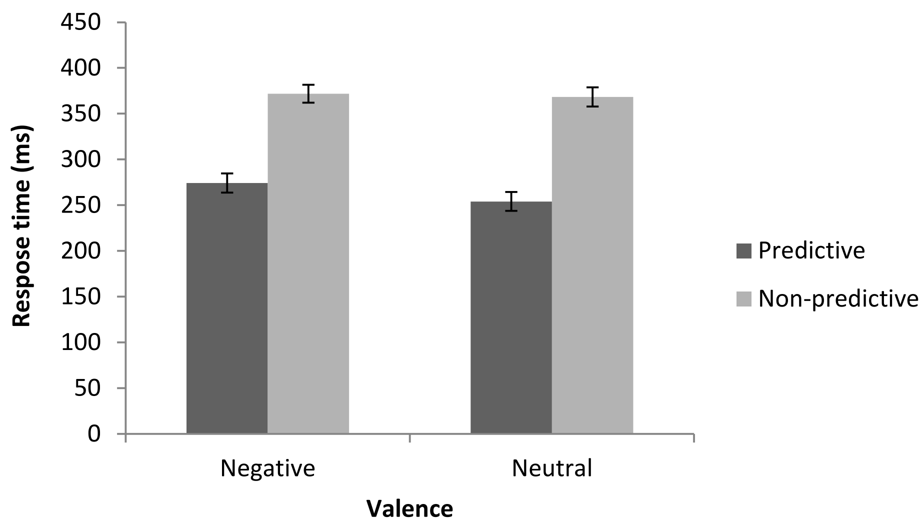

Figure 7.4. Mean response time for Go trials (ms) in the four tasks. Error bars are standard errors of the mean.

7.5.2 Correlations between response time and commission errors

Correlations between response time and errors of commission for each of the four tasks were investigated using simple Pearson product correlation coefficients (N = 40 in all cases). There was a significant negative correlation between response time and commission errors for the non-predictive–negative task, $r = -.72$, $p < .01$, as well as the non-predictive–neutral task, $r = -.58$, $p < .01$. Conversely, for the predictive–negative task, $r = -.04$, $p > .05$, and the predictive–neutral task, $r = -.10$, $p > .05$, there was no evidence of speed–accuracy trade-off.

7.5.3 Subjective measures

For each subject in each valence x prediction condition, the average scores on each of the 11 stress scale items (Table 7.1) were calculated. As with the behavioural results, separate 2 (emotional valence: negative vs. neutral) x 2 (task-relevance: predictive vs. non-predictive) repeated measures ANOVAs were performed on each of the 11 scale items. These were then followed with paired sample *t*-tests when appropriate.

For both task-related thoughts and task-unrelated thoughts there were no significant effects, $p > .05$. There was a significant main effect of valence for self-related thoughts, with self-related thoughts significantly higher for the neutral condition than the negative condition, $F(1, 39) = 6.22$, $p = .02$, $\eta_p^2 = .14$. For the tense item, there was a significant main effect of valence, with ratings for the negative condition higher than the neutral condition, $F(1, 39) = 37.21$, $p < .01$, $\eta_p^2 = .49$. Participants also reported being significantly unhappier after the negative condition than the neutral condition, $F(1, 39) = 45.18$, $p < .01$, $\eta_p^2 = .54$. There was a significant main effect of task-relevance for confidence, with confidence significantly higher in the predictive condition than the non-predictive condition, $F(1, 39) = 30.67$, $p < .01$, $\eta_p^2 = .44$. There were no significant main effects for the remaining items of physical fatigue, mental fatigue, motivation, task interest, concentration, nor any significant interactions for any of the 11 items, $p > .05$.

Table 7.1. Stress Scale items' means and standard deviations

	Predictive–negative	Predictive–neutral	Non-predictive–negative	Non-predictive–neutral
Task-related thoughts	67.15 (21.81)	60.00 (18.03)	62.38 (27.62)	62.64 (22.81)
Task-unrelated thoughts	37.13 (25.74)	43.62 (21.36)	39.25 (27.54)	43.02 (28.35)
Self-related thoughts^{v}	30.92 (24.01)	39.88 (24.87)	36.13 (27.49)	41.08 (27.45)
Physical fatigue	43.25 (26.01)	45.50 (24.57)	42.75 (28.33)	41.78 (23.64)
Mental fatigue	61.25 (23.45)	61.68 (25.16)	60.50 (29.50)	53.95 (25.91)
Tense^{v}	51.13 (25.13)	30.38 (24.71)	54.60 (27.00)	36.48 (25.69)
Unhappy^{v}	55.95 (26.80)	29.25 (25.00)	55.03 (27.54)	31.25 (23.91)
Motivation	51.13 (24.61)	57.45 (26.38)	53.63 (29.00)	53.40 (27.99)
Task interest	39.75 (25.14)	36.38 (25.19)	42.73 (25.70)	35.75 (27.45)
Concentration	63.72 (24.35)	60.00 (25.12)	63.20 (24.21)	58.50 (26.17)
Confidence^{p}	61.07 (24.61)	65.37 (21.30)	46.43 (22.92)	50.68 (24.03)

Note. ^{v} denotes a significant valence main effect, ^{p} denotes a significant prediction main effect, $p < .05$.

7.6 Discussion

The purpose of this experiment was to examine the impact of task-relevant (predictive) and task-irrelevant (non-predictive) negative and neutral picture stimuli on performance in modified SARTs. If negative stimuli inherently and regardless of task-relevance reduce commission errors with no cost to response speed, then a main effect for emotional valence (negative vs. neutral pictures) would be found for errors of commission, but with no increase in response time. Alternatively if the effect of stimulus valence on commission errors is contingent on task-relevance, a significant interaction would be found between emotion and task-relevance in which negative valence results in increased commission errors with task-relevant stimuli and reduced commission errors with task-irrelevant stimuli. In the present experiment, the effect was different to the possibilities that were initially considered. The inclusion of negative picture stimuli actually resulted in more commission errors, not fewer. There was moreover no evidence of an interaction. Although the effect itself was small ($\eta_p^2 = .09$), its direction may mean Wilson et al.'s (2015b) alternative explanation that the spider stimuli improved commission errors because spiders were readily distinguishable from the neutral pictures used in that study, not because they were negatively arousing (tension–anxiety inducing) is more plausible. Robinson et al.'s (2013) finding that the threat of unpredictable task-irrelevant shocks improves commission errors is harder to reconcile with the present findings. It could be that it is not the negative arousing nature of the stimuli, but the actual perceived threat (possible pain) of the stimuli that improve response inhibition. The present pictures based on self-report resulted in more unhappiness and more tension, but perhaps they were not perceived as "tangible" personal threats; despite their negative and at-times threatening nature (e.g., a picture of a gun pointed at the participant), the pictures could not inflict physical pain on the participants. Nevertheless this requires further research.

The negative pictures in the non-predictive task significantly increased errors of omission (failures to respond to the Go stimuli), relative to the other three tasks. This finding is similar to previous studies using low Go, high No-Go stimuli detection tasks (vigilance tasks), where errors of omission also increase when task-irrelevant negative picture stimuli are inserted into the task (Ossowski et al., 2011; Helton & Russell, 2011; although see Flood, Näswall, & Helton, 2014). This could be because the task-irrelevant negative pictures directly capture attention. Negative picture stimuli may also trigger further distracting thoughts (Ossowski et al., 2011; Smallwood, Fitzgerald, Miles, & Phillips, 2009). There was, however, no evidence from the self-report measures that the negative picture stimuli triggered a greater number of conscious thoughts (either task-related or task-unrelated thoughts). Indeed, negative pictures actually resulted in significantly fewer self-related thoughts. Perhaps the impact of the negative picture stimuli on omission errors is not because they trigger further thoughts about them, but instead because these pictures induce suppression of further thoughts about them (especially thoughts about them in the context of the individual). Suppression of these thoughts may demand executive control which competes with the ongoing task demands for attention (McVay & Kane, 2010). Another possibility is that suppression of these thoughts involves the same kinds of resources as suppressing a pre-potent motor response, given that negative pictures also led to more commission errors. Further investigation of this is required.

In regards to task-relevance a main effect was predicted, in which task-relevant picture stimuli would reduce commission errors. This was indeed the case. For a soldier in a battle space, any mitigation of action slips (e.g., friendly fire accidents) is more useful if it occurs without the concurrent trade-off in response time that is typical of factors which influence performance in SART-like situations. For example, recent research suggests slowing down soldiers' rates of firing may reduce the chances of some friendly fire accidents (Wilson et al., 2013b; 2014; 2015a), but it could make the soldiers more vulnerable to being engaged by genuine enemies first. The current findings suggest that the use of reliable warning cues could be one way to reduce the likelihood of friendly fire accidents occurring without slowing down responding, or firing. Such technology could be along similar lines to Blue Force Tracking systems, which use GPS technology to report the location of allied soldiers on a digital map (see Bryant & Smith, 2013; Ho et al., 2013). One drawback of technological aids such as these though is that they cannot recognise non-combatants such as civilians. Another, more futuristic, possibility would be the use of technology that allows soldiers to see through walls.

The effect of predictive stimuli also lends general support for a strategic perspective of SART performance (Finkbeiner, et al., 2015; Helton et al. 2011a; 2011b). Participants appear to take active advantage of any information which helps them to withhold responses to No-Go stimuli. It is unlikely that a subject who was perceptually decoupled would be able to process and take heed of the cues that the predictive stimuli provided. In regards to the role of conscious thoughts on commission errors in SART-like tasks, there were no significant differences between the predictive conditions, where commission errors were relatively rare, and the non-predictive conditions, where commission errors were much more prevalent. This lends some support to the perspective that the causative impact of either the lack of conscious thoughts (mindlessness) or high reports of task-unrelated thoughts (mind wandering) on actual SART performance is highly overestimated by many researchers (Smallwood, McSpadden, & Schooler, 2007; Smallwood & Schooler, 2006). SART performance may be better explained by mechanisms like Peebles' and Bothell's (2004) dynamic response strategy model, which does not need to account for either conscious states or the contents of consciousness. SART commission errors are the result of two task demands, to respond as quickly as possible to Go stimuli yet to be accurate in withholding to No-Go stimuli. These requirements appear to be impossible to satisfy simultaneously without prior warning of an impending No-Go event. If the nature of the stimuli is cued accurately, the participant has more time to respond overall and there is, therefore, no penalty to perform encode and check, instead of simply encode and click.

The present experiment casts some doubts regarding the likelihood that tense arousal (tension) or anxiety itself improves response inhibition. It may be that the mechanism needs to be more specific, such as the presence of actual personal threat, but this requires further research. The success of task-relevant warning cues in reducing commission errors in the current experiment has implications for applied contexts. If soldiers could be alerted to the presence of allies or civilians *before* they confronted them, this could reduce rates of friendly fire. The present results also provide more evidence in support of a response strategy perspective of the SART.

7.7 Summary

Anxiety-provoking stimuli appear to impair response inhibition. The presentation of negative pictures led to participants making more commission errors but also having slower response times. Considering Chapter 6 and 7 together, the different experiment findings may appear to be incongruent. However, the improved SART performance seen in Chapter 6 may be explained by the increased ease of discriminability of the spider stimuli, as opposed to a beneficial effect of anxiety. The current experiment also found that providing reliable warning cues for imminent No-Go stimuli in the SART led to fewer commission errors and faster response times to Go stimuli. This is notable as most other task modifications that reduce commission errors incur a cost in the form of longer response times to Go stimuli (i.e., speed–accuracy trade-off). If dismounted soldiers could be given reliable forewarning of the appearance of friends or civilians (No-Go stimuli), this could lower the chances of response inhibition failures, and crucially, without a concurrent reduction in all-round response or firing speed. One issue with this however is developing technology that could give soldiers reliable warning cues that cannot be hijacked by enemy forces. This is a formidable challenge. Current technological aids exist for the purpose of correctly identifying allied soldiers but problems arise when reliability is less than perfect (which is often the case) and when there are lags or delays in the incoming information (Boyd et al., 2005; Bryant & Smith, 2013; Penny, 2002). Furthermore these technologies do not recognize foes or non-combatants.

8 General Discussion

Each of the Chapters 2 to 7 are self-contained studies with their own discussions and conclusions, therefore this Chapter will briefly reiterate highlights and limitations and address this body of work as a whole.

The primary aim of this thesis was to investigate whether modification to the traditional SART could be used to model friendly fire in some battle scenarios. A secondary aim was to provide evidence capable of adjudicating between the two competing accounts of the genesis of commission errors in the SART, which is widely assumed to provide a valid measure for distinguishing people in terms of their ability to sustain attention. That is, do commission errors occur because the boring repetitious nature of the task leads to mind wandering, states of mindlessness and perceptual decoupling or do commission errors occur because conflicting task instructions induce dynamic choices between strategies that control the incidence of failures to inhibit a strong tendency to initiate a Go-appropriate response on every trial? The experiments also provided opportunities to explore several other more specific aspects of performance in SART-like situations, such as: the impact that anxiety has on failures to inhibit or control a high strength response (Chapters 6 and 7); whether commission errors and response times in SART-like contexts change disproportionately as Go to No-Go proportions change (Chapters 2 and 4); and the impact that manipulating the physical action required to execute a response has on response inhibition (Chapter 5).

8.1 Friendly fire

Chapters 2 and 3 investigated whether modification of the traditional SART could provide a useful model for some battlefield scenarios. Furthermore, Chapters 2 and 3 explored whether failures of response inhibition may be contributing to some friendly fire accidents. Experiments that were relatively applied in nature were conducted, using laser-tag guns and live human actors to simulate a battlefield environment. Proportions of friends relative to foes were manipulated, and participants completed firearm versions and computer versions of tasks that preserved the essential high Go, low No-Go characteristics of the traditional SART.

The same sort of behaviour that is seen in the traditional SART was observed in the firearm tasks. High-foe (high Go) or target-rich environments led to a much higher rate of friendly fire errors (commission errors) than comparative lower-foe (low Go) or target-sparse environments. In Chapter 3, when response times were measured, the speed–accuracy trade-off that is typical of SART-like tasks was observed. When the proportion of foes in an environment was high, participants became faster at firing at foes. This coincided with more failures of response inhibition, or friendly fire, on the rare occasions that they confronted friends. It appeared that a pre-potent motor program was operating when subjects were using firearms too. As to the underlying cause of the pre-potent motor—or “fire”—response, from the findings in Chapters 4–7 it seems likely that weapons operators adopt an encode and “shoot” response strategy, analogous to the encode and click strategy (Peebles & Bothell, 2004) that subjects in high Go tasks like the SART favour. In a battle space containing many foes with few allies or non-combatants, the benefit of an encode and shoot strategy is apparent as this ensures shooters are quicker to fire. However, it also means they are less likely to be able to withhold when the situation requires it, for example when they confront an ally or a non-combatant.

In Chapters 4–7, a more traditional, basic experimental approach was taken to investigate how and why failures of response inhibition occur in High Go, low No-Go (high foe or target-rich) tasks or environments. In Chapter 4, the effect that the relative proportions of friends to foes in a battle environment (Go stimuli proportion) may have was investigated further. Consistent with the findings in Chapter 2, there was a disproportionate decrease in response inhibition as Go stimuli proportion rose. Between 65–80% Go stimuli, participants became markedly faster at responding to Go stimuli and made fewer successful withholds to No-Go stimuli. This has implications for the makeup of a battle environment. It suggests that friendly fire resulting from response inhibition failure is at its highest risk in environments where foes are inter-mixed with allied soldiers and/or non-combatants, and foes account for at least two-thirds of the individuals present. This is particularly the case for engagements that are fast-paced and involve enemy combatants being confronted in rapid succession. For a dismounted soldier, operations in urban terrain often present these challenges. These implications may also apply to the operation of automated weapons systems, where operators are only required to confirm or reject identified targets following the automatic detection and locking-on of the target by the system automation. In Chapter 5, computer-based modifications to the SART were used to investigate the impact that artificially extending the response duration had on the rate of commission errors and self-report measures relating to mental and physical demands. Similarities were drawn with the use of modern automated weapons systems. These automated systems typically require little manual input from the human operators. The findings from Chapter 5 suggest that while this may shorten the time needed for an operator to fire a weapon, it may increase the likelihood of friendly fire incidents. This has implications for the design of automated weapons systems. The decision to remove certain subtasks that the human operator would otherwise have to perform may need to be reconsidered. For example, removing the requirement for the human operator to aim at a target because the automation manages this task instead may allow the operator to fire at more targets in a shorter timeframe, but could make them vulnerable to response inhibition failures. At the very least, perhaps operators could be alerted by the system when their rate of firing nears the point where being able to withhold fire will be difficult. Further research is required here however.

In situations where consecutive enemy targets are being engaged in quick succession, weapons operators may struggle to prevent themselves from firing again when it is instead necessary to withhold. The knowledge that the development of a pre-potent motor response in a soldier could lead to failures to withhold fire could be useful information to a battle commander, who could use it to identify battle environments where the chances of friendly fire may be particularly high given the proportion of enemies relative to friends or civilians present.

The finding that adaptations of the traditional SART may be able to assist understanding of accidents involving response inhibition failure is likely not limited to military operations alone. It may also be applicable in other contexts where weapons operators must make shoot/no shoot decisions, such as law enforcement and even hunting accidents. Law enforcement officers, like soldiers, can be faced with shoot/no-shoot decisions which must be made within fractions of a second (Meyerhoff et al., 2004). Hostage situations are one example of this. Response inhibition failures could also be relevant to some hunting accidents, particularly in situations where hunters have violated best practices by “snap shooting.” This occurs when a shooter sees a target and fires upon it within one continuous movement (Green, 2003). Hunters may be vulnerable to making motor inhibition errors in types of hunting where it is common to fire multiple, consecutive shots in short spaces of time, such as duck or turkey hunting (although see Wilson & Bridges, 2015, who suggest cognitive biases are often implicated in hunting accidents). Whether action slips are contributing to law enforcement and hunting accidents requires further research.

It is important to note that while the findings here have application for close quarters combat and military operations in urban terrain, they may not apply to other battle environments. For example, many incidents of air-to-ground or ground-to-air friendly fire are probably due to factors unrelated to response inhibition, such as poor visibility leading to genuine target misidentification. These sorts of mistakes, where the shooter believes he has the correct target when he in fact does not, can be distinguished from the error or slip that is made when the shooter is aware that the target should not be responded too, but cannot physically withhold a motor response.

An obvious limitation of this research is that the conditions in laboratory experiments are far different from the typical conditions in a battlefield. Replicating real-world scenarios is a common challenge for laboratory research, particularly for a scenario such as war. It is often impossible to reproduce actual conditions. Despite genuine attempts to achieve reasonable ecological validity through the experimental paradigms used (specifically Chapters 2 and 3), the conditions were still far-removed from those typically experienced by soldiers on a battlefield. Soldiers frequently experience sleep deprivation, physical and mental fatigue, and stress or anxiety (Hart, 2004; Meyerhoff et al., 2000). Sleep deprivation and fatigue have been shown to negatively impact decision making (O'Rourke, 2003). One study using the SART showed that commission errors were positively correlated with self-reported sleepiness measures (Manly, Lewis, Robertson, Watson, & Datta, 2002). It could be speculated that response inhibition errors will be more likely when soldiers are sleep-deprived, which is often the case. Future research is needed to investigate the impacts of sleep deprivation and fatigue. Nevertheless, one factor that was explored in the current thesis was anxiety. While this was not incorporated into the firearm tasks, it was examined in computer-based SARTs in Chapters 6 and 7, enabling greater experimental control. The findings suggest that response inhibition, and therefore friendly fire errors, may be exacerbated when soldiers experience acute anxiety in a battle space. This will be discussed in more depth in the following section (8.2).

Another limitation concerns the participants who were University students as opposed to trained soldiers. Further research is required to see whether the findings with students will generalise to combat-trained people. As to the differences that might hypothetically exist between trained riflemen and university students, in terms of shooting behaviour in high-foe, low-friend (target rich) battle environments, this is an interesting question. Untrained participants took on average 1,111 ms to fire on a foe in the firearm SART (Chapter 3) and even with this arguably long response time they committed friendly fire on one third of their friends. It is expected that trained and highly skilled soldiers will be able to execute the fine motor movements required to fire much more quickly than novice students. Consequently if the ubiquitous relationship between speed of response and probability of commission error applies here too then they will be expected to make a higher proportion of friendly fire errors than novice students. However, if trained soldiers were able to pace themselves and respond at a slower rate, fewer friendly fire errors may occur.

Crucially though, soldiers may not be able to afford to take an approach where they deliberately slow their speed of firing in real engagements such as those common in close quarters combat. They are often fighting against other combatants experienced with the use of firearms, or at least individuals who are not likely to be adopting the more conservative strategy described here. While today's peacekeeping operations typically adopt the approach of not using force unless in self-defence, the hostiles these soldiers face often have different attitudes to this. Instead soldiers must attempt to emphasize speed and accuracy equally, in the same way that SART participants are instructed to do. Indeed, "speed" is one of the principles of room clearing in military operations. Rather than referring to how fast the room is entered though, speed refers to how quickly the enemy can be eliminated (U.S. Department of the Army, 1993, 2011). Reaction times in urban warfare are often extremely short (Committee on Defense Intelligence Agency Technology Forecast, 2005; Glenn, 1996). While the advanced skill level that trained soldiers possess is likely to bestow them with an enhanced ability to withhold their fire *at a given speed* (e.g., relative to lesser-trained individuals), they will likely be firing at speeds beyond those of a lesser-skilled person. In essence, there is a point where soldiers in active duty will be vulnerable to response inhibition errors also. Further, consider that for a soldier in a battle space the consequence of delaying a response for too long can be instant death by enemy fire. This is in stark contrast to a participant in a computer-based SART, where a self-imposed delay in responding will increase their average response time but carry no personal consequences. Soldiers are surely not immune to the evolutionary instinct of survival. There is an undeniable advantage (regardless of whether it is perceived or genuine) to firing quickly in order to avoid being killed first, even if it means the risk of friendly fire is slightly raised.

Research involving trained soldiers is needed to explore these possibilities however. At the time of writing this work, I was informed of a just-completed experiment conducted at the United States Army Research Laboratory (Head, personal communication). Researchers had professional infantrymen perform a marksmanship task where they fired at briefly-presented pop-up targets occurring in rapid succession. When targets representing foes, or Go stimuli, accounted for the majority of targets (a target rich environment), infantrymen reportedly failed to withhold to rarely-occurring friendly targets (No-Go) over one third of the time. Although these are preliminary findings, this is early evidence that trained soldiers may be just as vulnerable to friendly fire errors in high Go (high foe) contexts.

The current body of work suggests authors of future research may benefit from considering the impact of differing friend to foe proportions on rates of friendly fire. Most researchers employing shoot/no-shoot tasks use 50:50 proportions (e.g., Bryant & Smith, 2013; Ho et al., 2013; Johnson & Murello, 1999; Neyedli, Hollands, & Jamieson, 2011; Patton, 2014; Scribner, 2002; Scribner, Wiley, & Harper, 2007; Wang, Jamieson, & Hollands, 2009), however the current research indicates that different friend to foe proportions can have vastly different consequences. Pre-potent motor responses may only develop, or at least begin to noticeably impair response inhibition, with foe proportions upwards of .65–.70. By not examining conditions where foe proportions are higher, researchers may be unknowingly neglecting the impact that pre-potent motor responses and response inhibition might have during their experiments.

Exploring the impact of cognitive load on soldiers would also be useful. Increasing technology is providing soldiers with more information than ever about their surroundings and current situation, leading to a risk of cognitive overload (Hart, 2004). Scribner (2002) had trained military shooters perform a pop-up targets marksmanship task while completing maths problems (a dual-task scenario). He observed that 3-times more friendly targets were engaged in this dual-task condition relative to the shooting-only condition. More recently, Head and Helton (2014) found that participants completing a modified SART alongside a verbal free-recall memory task had poorer response inhibition performance.

Further research is needed to test trained soldiers under conditions which are closer to combat environments. One way to achieve a reasonably high level of fidelity, without encountering the risks associated with a real battlefield, is to employ simulation methods. Simulation methods involving shoot/no-shoot paradigms have previously shown success in military experimentation (see Neyedli et al., 2011; Patton, 2014).

8.2 The impact of anxiety on response inhibition

Chapters 6 and 7 investigated the impact that anxiety provoking stimuli has on the SART and response inhibition more generally. This served two purposes: Firstly, these Chapters indicated the potential impact that acute battlefield stress may have on the likelihood of friendly fire accidents in environments that share characteristics with SART-like tasks. Secondly, these Chapters addressed the broader question of whether anxiety enhances or impairs response inhibition in general, which is unclear from previous research.

Previous research generated differing findings about whether anxiety or stress enhances (Robinson et al., 2013) or impairs (Patton, 2014) response inhibition. After Robinson and colleagues observed that task-*irrelevant* anxiety could improve response inhibition, the experiment in Chapter 6 was conducted to see whether the same effect was seen with task-*relevant* anxiety by using anxiety-provoking spider picture stimuli as Go or No-Go stimuli in a modified SART, instead of the typical digit stimuli (1–9). Indeed, response inhibition was improved when spider pictures were employed relative to a SART containing digit stimuli. However, an alternative explanation was that the spider and non-spider stimuli were simply more visually discriminable than digits used in the traditional SART, leading to reduced commission errors at no cost to response time. Response time may have even been shortened (although this difference was not statistically significant), indicative of a more *general* improvement in SART performance which could also support the ease of visual discrimination viewpoint. Therefore in Chapter 7, an experiment was conducted that compared anxiety provoking stimuli of negative valence and high arousal with neutral stimuli in both task-relevant and task-irrelevant roles. The negative and arousing pictures provided no benefit to performance and in fact even increased errors of commission, regardless of whether the pictures were task-relevant (predictive) or task-irrelevant (non-predictive). It appears that the improved response inhibition observed in Chapter 6 was due to spider stimuli being more visually discriminable, as opposed to the idea that their anxiety-provoking characteristics improved participants' ability to withhold to No-Go stimuli. This appears to conflict with Robinson and colleagues' (2013) findings. Perhaps the difference is due to the induction of pain in Robinson et al.'s study. Participants in their study received painful shocks and perhaps this was the means to which response inhibition was improved.

The findings from Chapter 7 suggest that in stressful environments the likelihood of inhibition failures could be higher. This may be problematic for environments where action slips can occur. There are implications for weapons operators, particularly those engaged in intense close-quarters combat. The experience of stress in combat is well-documented. It has been shown to impact upon aspects such as decision-making, reaction times, and energy levels (Moore et al., 2012) and it is thought to increase the likelihood of friendly fire (Shrader, 1992; Steinweg, 1995). Law enforcement officers can also be exposed to highly stressful situations where they must quickly make shoot/no-shoot decisions (Anderson, Litzenberger, & Plecas, 2002). Inducing stress during the training of soldiers and law enforcement officers is one method of managing the impact of anxiety (Nieuwenhuys & Oudejans, 2011; Saunders, Driskell, Johnson, & Salas, 1996). Acute combat stress currently receives considerable attention in military training (Moore et al., 2012), however to my knowledge the impact that stress may have on weapons operators' motor response inhibition capability has not yet been addressed. It would be beneficial to also employ objective measures of stress, such as galvanic skin response and heart rate measurements, to look at the relationship with response inhibition.

In terms of mitigating the effects of anxiety on response inhibition in other settings, in some cases engineers can redesign systems so that intrusions by negative or anxiety-inducing stimuli can be prevented or mollified. Personnel can be screened to gauge resiliency to stimuli that they may be exposed to in their roles. For roles where system operators are likely to be exposed to negative or anxiety-inducing stimuli, personnel that are less-vulnerable to the impacts of these stimuli should be favoured (also see Helton & Russell, 2011).

With regards to task performance, the overall findings here provide clear support for a resource or overload model (e.g., Parasuraman, Warm, & Dember, 1987) as opposed to an underload model (e.g., Manly et al., 1999). An interesting question though is whether a unitary resource model (e.g., Kahneman, 1973) or a multiple resource model (Wickens, 1984) is a better fit for interpreting how cognitive load affects response inhibition in SART-like tasks. While examining this was not an aim of the current body of work, the findings may provide more support for a unitary model given the negative impact that acute anxiety had on performance. This question appears to have received little attention within the SART literature, although Shaw et al. (2013) found evidence to support a unitary resource model after examining the changes in cerebral blood flow velocity in participants performing a SART. Authors of future research may benefit from examining this question.

8.3 The SART is not a useful measure of sustained attention

This body of research provides considerable evidence that errors of commission are not a useful index of perceptual decoupling in SART-like tasks. Instead, the findings here support the perspective that SART performance is instead a measure of simple response strategies and response inhibition.

Proponents of a perceptual decoupling perspective ascribe commission errors in SART-like tasks to participants' absentmindedness resulting from under stimulation and boredom. Chapters 4–7 provided means to investigate this claim, through considering participants' subjective reports alongside their SART performance.

In Chapter 4 the impact of manipulating the relative Go to No-Go stimuli proportions was investigated. The increase in commission errors and shortening of response times (the typical speed–accuracy trade-off) as the proportion of Go stimuli increased coincided with an increase rather than a decrease in task-related thoughts. Task-unrelated thoughts, which are often used by perceptual decoupling advocates as indicators of mind wandering (Smallwood et al., 2003), were not associated with any of the SART performance measures and remained low over each condition.

In Chapter 5, the physical movement required to execute responses to SART stimuli was altered. Requiring participants to manually move a mouse cursor before they could click a button to respond led to slower response times and fewer commission errors, or improved performance. Proponents of a perceptual decoupling perspective would posit that the performance improvement was due to the additional manual movement offering increased exogenous support of attention. This did not appear to be the case however, as there were no detectable differences in participants' reports of mental fatigue or mental demand between the manual movement SART and the automatic movement SART. The findings instead supported a response strategy or inhibition perspective; making the response movement take longer gave participants more time to inhibit a pre-potent motor response, resulting in fewer commission errors. The improved performance was due to physical or motor factors rather than mental or perceptual factors.

Chapters 6 and 7 addressed the impact of anxiety-provoking stimuli on SART performance and response inhibition. In Chapter 6, reported task-related thoughts increased from pre-task to post-task for the SARTs. Task-unrelated thoughts on the other hand showed the exact opposite. Participants were evidently focused on the tasks as opposed to perceptually decoupled. Errors of commission and response time were significantly correlated with task-related thoughts. That is, higher task-related thoughts were associated with faster response times and increased commission errors. Again this is in direct contrast to a perceptual decoupling perspective. In Chapter 7, neutral (less attention-capturing) or negative (more attention-capturing) pictures that were either predictive (task-relevant) or non-predictive (task-irrelevant) of No-Go stimuli were incorporated into the SART. Consistent with a response inhibition or response strategy perspective but not a perceptual decoupling perspective, performance on the modified SARTs was more dependent upon the predictive value of picture stimuli as opposed to their attention-capturing nature. In fact, the negative picture stimuli appeared to actually impair performance. This does not fit with the idea that in SART-like tasks, speeded responses and commission errors are due to participants becoming perceptually decoupled because of the boring and monotonous nature of the task. Additionally, that participants were able to take heed of the cues that warned them of imminent No-Go stimuli, suggests that subjects were perceptually engaged with the task. Explanations derived from perceptual decoupling appear incapable of accounting for the relationships between performance and self-reports observed in the experiments reported here. SART performance instead primarily reflects response strategies used by participants as well as response inhibition. While Peebles & Bothell (2004) do an excellent job of demonstrating the involvement of response strategies in SART performance, less literature appears to exist on the mechanisms behind the response inhibition aspect of performance in this task. Future research is needed to improve understanding of this.

There may however be some involvement of sustained attention during the SART. Inhibiting the pre-potent motor program that develops in the task requires the supervisory attention system (see Helton et al., 2005) to intervene. SART performance is likely instead associated with executive control of the pre-potent motor program, or an internally directed form of attention (Head & Helton, 2014; Helton et al., 2009a; 2010). However the task is likely not measuring sustained attention in the sense that the majority of authors using the SART intend, which is the measurement of *externally-directed* attention, for example perceptual awareness (Helton et al., 2010).

Finally, there are potential limitations with the use of subjective reports when adjudicating between the two competing theories of SART performance. Regarding the DSSQ (Matthews et al., 1999; Matthews et al., 2002) it could be argued that the retrospective nature of the reports could lead to subjects forgetting their true state of mind during the task by the time they complete the questionnaire. Note that the SART is a very short task though (approximately 4 min) and the DSSQ is a widely-used and accepted measure for investigating task-unrelated and task-related thoughts. Furthermore, alternative methods such as thought probe techniques (see Smallwood et al., 2003, 2004) where subjects are interrupted during the task and asked to rate their thoughts have issues themselves, such as the possible impact of performance appraisal (e.g., if a participant had made an error on the preceding trial, are they then more likely to rate their thoughts as being off-task?) and the degree to which the task interruption affects the task itself. As for using subjective measures in general, the obvious lack of objectiveness is one concern. However until improved methods are developed with which to objectively measure mind wandering, thought scales such as the DSSQ are probably the most useful methods for differentiating between the perceptual decoupling and response inhibition explanation of SART performance. Future researchers should attempt to actively manipulate mind wandering however.

8.4 A single solution to prevent response inhibition failures?

When considering how failures of response inhibition can be mitigated in applied settings, the findings of the work reported here are somewhat bleak. It appears that there is (currently at least) no single solution. Attempting to mitigate the action slips observed in SART-like tasks by preventing mindlessness or mind wandering will not work, because these action slips do not appear to be caused by mindlessness, mind wandering, or sustained attention failures. From the perceptual decoupling perspective, one way to mitigate these errors would be to present additional stimuli to provide exogenous support of attention.

Take the example of a soldier fighting in an intense battle environment. If the soldier is vulnerable to failures of response inhibition and commits friendly fire the perceptual decoupling perspective suggests these errors are caused ultimately by lack of environmental variety, because variety is necessary to support attentional engagement and to prevent boredom and absentmindedness. Adding additional stimuli in the form of an audible tone that intermittently played over a soldier's earpiece for example would be one way to increase support of exogenous attention. From a perceptual decoupling perspective this could help to mitigate action slips and friendly fire accidents by preventing perceptual decoupling in the first place. Clearly this solution has problems. Chapters 4 and 5 show commission errors in the SART are more closely related to response inhibition or response strategies, rather than attentional failures. Furthermore, in Chapter 7 the condition in which stimuli were the most attention-capturing led to the poorest performance—this is the opposite to expectations from a perceptual decoupling perspective. Absentmindedness does not adequately explain commission errors in the SART, and attempting to prevent these errors by further increasing attentional demands will not mitigate the errors in real-life SART-like situations. If anything this will exacerbate errors of response inhibition (see also Head & Helton, 2014; Helton & Russell, 2011).

Nevertheless, several of the experiments here do demonstrate how altering the SART can improve participants' ability to withhold responses and thereby reduce commission errors. In Chapters 2, 3, and 4, decreasing the relative proportion of Go to No-Go stimuli led to fewer commission errors. Though, one issue here is that a system operator in a real-life SART-like context will not often have control over "Go proportion." Nonetheless, knowledge of a situation's typical Go proportion (i.e., the amount of times an operator will be required to make some motor response relative to the amount of times they will be required to withhold that motor response) is useful information to have when designing a system in the first place, and when considering factors which might affect an operators' likelihood of making response inhibition errors. In Chapter 5, extending the physical movement required to execute responses also reduced errors of commission. Head and Helton (2013, 2014) observed similar findings, as did Seli and colleagues (2013) when they delayed responses by making subjects wait for an audible cue before they could respond. Altering task instructions to emphasise accuracy over speed also leads to fewer commission errors (Seli et al., 2012). However, while methods such as these reduce commission errors, they usually incur a performance cost of longer response times, or reduced speed (speed–accuracy trade-off). While this may be acceptable in some real-world situations (e.g., when a reduction in speed is worth the lowered risk of making an action slip), in other cases the speed-cost may be unacceptable. For example, a dismounted soldier fighting in a cluttered urban environment can probably not afford to have firing speed delayed, even if it reduces the chances of committing a friendly fire error. Part of a shooter's effectiveness involves the ability to fire shots rapidly. Instructing (or forcing, e.g. through mechanical interventions) a soldier to slow down his or her firing speed may not be acceptable. Instead, other tactics may need to be explored. For example, in the Chapter 6 experiment, picture stimuli improved participants' ability to withhold responses without the typical cost to response time. While it was initially unclear whether this was due to the anxiety-provoking nature of the pictures or alternatively the increased discriminability of Go and No-Go stimuli, further investigation suggested that discriminability not anxiety was responsible (see Chapter 7). Smallwood (2013) also found that SART performance was improved when the visual salience of stimuli was enhanced. Comparable findings have also been shown with an auditory version of the SART, when increasing the salience of verbalised words improved SART performance (Roebuck, Guo, & Bourke, 2015). The findings in Chapter 6 suggest that increasing the visual salience or discriminability of allied soldiers (relative to foes and non-combatants) could enable faster recognition leading to shorter response times as well as fewer commission errors. This could be achieved by changing aspects of the uniform so that allied soldiers "stand out" more to each other. However there are obvious issues with this. Firstly, as a result the uniform could also be more salient to foe soldiers. Secondly, it could create confusion if the enemy acquired the uniform. Thirdly, this method would provide no protection for civilians who may be victims of collateral damage. One way around this could be to train soldiers to pick up on certain cues that could allow them to more quickly differentiate between allied and foe, or rather, allied, foe, and civilian. Prior research has documented the success of cue-based training in other domains (e.g., Wiggins & O'Hare, 2003). Increasing the speed of detection could help mitigate errors of response inhibition, as was found in the Chapter 6 experiment. One simple method to mitigate air-to-ground friendly fire has involved training pilots to recognise certain visual features or "markers" on friendly forces on the ground (Wise, 2011). Such "friendly markers" include reflective panels, smoke, and glint tape. While this may be partly effective for reducing air-to-ground incidents, it probably has limited usefulness for mitigating ground-to-ground incidents for which response inhibition plays a role. If the results from Chapter 6 are anything to go by, increasing the visual discriminability of friendly soldiers may slightly reduce the likelihood of friendly fire, but will not prevent the accidents altogether. Besides, if making allies more easily discriminable from foes and non-combatants also makes allies more visually salient in general, this would allow the enemy to identify them with less difficulty. A more promising avenue to explore may be the recent work of Biggs and colleagues, who are investigating whether civilian casualties may be mitigated through "active-response inhibition training" (Biggs, Cain, & Mitroff, 2015).

Chapter 7 showed that predictive cues that alerted participants to the onset of imminent No-Go stimuli also reduced commission errors without the associated cost to response time—in fact response times to Go stimuli were also significantly improved when participants could rely on these warning cues. This has also been seen in previous research with the SART (Finkbeiner et al., 2015; Helton et al., 2011a; 2011b) While the main point of including predictive and non-predictive stimuli was to see whether the impact of emotional stimuli on SART performance interacted with task-relevance, the findings could also be considered in terms of how friendly fire errors might be reduced at no cost to response time. Presenting warning cues can improve people's ability to withhold responses when required without slowing their responses down. The challenge here though is being able to provide people with warning cues that serve this purpose. Some current technological aids can do this to a degree, such as Blue Force Tracking (BFT) systems (Armenis, 2010; Bryant & Smith, 2013) and Identify-Friend-Foe (IFF) systems (Cruz, 1996; Seah & Deepan, 2012). Technological interventions may be useful, however problems arise with these when reliability is less than perfect (Dzindolet et al., 2001; Kogler, 2003; Parasuraman & Riley, 1997). Furthermore, these systems often have lags in the presentation of information (Boyd et al., 2005), particularly in urban environments where dead spots are common. Drawbacks such as this can significantly reduce the usefulness of these systems (Penny, 2002). Moreover, current technologies cannot alert soldiers to the presence of non-combatants such as civilians (or any individual that does not also possess the appropriate and functioning technology).

A more futuristic possibility would be to give soldiers the ability to see their potential targets ahead of time. One method to do this would be to enable soldiers to see through walls and other opaque objects which individuals may be using to shield themselves. This would be one way to effectively give soldiers a warning cue that could prevent them from failing to inhibit a pre-potent firing response without them having to slow down their speed of responding, akin to what was observed in Chapter 7. When warning cues are sufficiently advanced to be useful, people can use them to effectively withhold responses when required while also maintaining sufficient response speed. In relation to Peebles' & Bothell's (2004) model of SART performance, providing reliable cues ahead of time makes it beneficial for participants to adopt an encode and click strategy. Indeed technology allowing people to "see through walls" has been developed (in a sense, at least), with University College London researchers creating a device that uses WiFi radio waves to detect the presence of people through walls (Chetty, Smith, & Woodbridge, 2012). However while the device can detect a person's speed, location, and direction through a one-foot-thick brick wall, it will not provide an indication as to whether the individual is a foe, friendly, or civilian. Nevertheless, technology with this capability is likely to be developed in the future. It will undoubtedly be highly sought after by the military as well as law enforcement.

Unfortunately, as long as battles continue to be conducted in fast-paced environments where enemy combatants share space with allied soldiers and non-combatants, friendly fire accidents are still likely to occur. Until soldiers have the ability to reliably see potential targets ahead of time and classify individuals as friendly, non-combatant, or foe, the best solution to avoid friendly fire would be to avoid battles in these circumstances altogether. Otherwise, the use of technological aids such as BFT devices may be the next best option. Despite their limitations in urban environments, these tools are probably the closest means to receiving warnings about at least some of the No-Go stimuli (e.g., allied soldiers who are also using the technology) in the surrounding environment.

8.5 Basic research is crucial to solving real-world problems

That the SART is able to assist understanding of such an applied, real-world problem as friendly fire is evidence of the importance of basic research. On one hand, applied research has undoubtedly revealed crucial factors involved in friendly fire incidents and countless other real-world problems. Applied research has provided insight as to some important macrocognitive factors involved in friendly fire. However as Wilson et al. (2007) relate, the factors cited are often broad terms such as reduced situation awareness (Harris & Syms, 2002), communication failures (Schraagen et al., 2010), poor co-ordination (US Congress, OTA, 1993), or inadequate training (McNew, 2008). While these findings are indeed highly useful, at times they risk neglecting the involvement of microcognitive constructs and in doing so may not afford a sufficient understanding of the underlying causes of friendly fire. The design of training methods, operational procedures, and equipment to mitigate these accidents will not be as successful without a proper understanding of the underlying causes of friendly fire accidents.

Basic research is able to provide insight on the microcognitive constructs involved in behaviours. Ultimately, combining basic and applied research to understand a real-world issue will produce the best results. The two methods are complementary in nature (Wilson, Helton, & Wiggins, 2013a). As O'Hare and colleagues (O'Hare, Wiggins, Williams, & Wong, 1998) point out, the careful integration of theory and practice is essential when designing systems and training. Furthermore, basic and applied methods appear to be converging, driven by advances in technology. Simulations are becoming more immersive and life-like than ever (e.g., Loomis, Blascovich, & Beall, 1999; Risto & Martens, 2014). The increased portability and affordability of complex testing equipment, such as portable eye-tracking and EEG devices, are allowing the precise measurement of variables in real-world contexts, in a way that was formerly not possible outside of a testing laboratory. Moreover, some real-world tasks—such as controlling unmanned vehicles—are beginning to look more like computerised tasks or simulations themselves which would not look out of place in a psychological testing laboratory.

The current body of work demonstrates that response inhibition, a microcognitive construct, appears to be a factor in some friendly fire incidents. Up until now the role of response inhibition in friendly fire has received little attention. Perhaps this was because a basic research approach was thought to be unable to contribute much to such an applied real-world problem, and as a result, predominantly applied research approaches have been used. While applied research has uncovered important factors involved in friendly fire accidents, basic and applied research are complimentary and as such should be used together.

8.6 Conclusion

The SART may provide an empirical model for friendly fire accidents in some battle scenarios. Fast-paced engagements, in environments where high proportions of foes are inter-mixed with a small number of friends or non-combatants, appear to cause the same sort of behaviour typically seen in the computer-based SART. That is, a pre-potent motor response develops making it more difficult for individuals to withhold responses (prevent firing).

The relevance of the SART to weapons operations in battle spaces may further increase. Battles are predicted to be increasingly fought in urban environments, where engagements are conducted at high speed, short distances, and soldiers share the battle space with foes, allies, and civilians. Additionally, increases in automation may mean that many weapons operators are engaged in control tasks which resemble the SART. For example, their roles may involve responding to targets displayed on a computer screen which have been pre-selected and acquired by the system automation; essentially human operators will only be required to confirm or reject targets. The current body of work suggests that conditions such as these are highly conducive to response imbibition failures, and thereby friendly fire accidents.

The research into how the SART may apply to weapons operations is not yet conclusive, as further research must be conducted using participants that are more experienced with firearms, and in experimental environments that are able to better capture the essence of war. However the current research does provide a solid foundation for which future research can be built upon.

As to the underlying mechanisms responsible for commission errors in SART-like tasks, this body of work provides further evidence that commission errors are primarily due to failures of response inhibition and response strategies, as opposed to perceptual decoupling. Factors that may further exacerbate these errors include higher proportions of Go stimuli, a reduction in the physical requirements needed to execute responses, and high-stress or high-anxiety environments. Providing cues that reliably warn people of imminent No-Go events is one way to mitigate commission errors without impairing response times.

Finally, this thesis is further evidence that basic empirical research in the psychological laboratory can be useful for investigating highly applied and complex real-world problems.

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Appendix A

Friendly Fire and the Sustained Attention to Response Task

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