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Friendly Fire and the Sustained Attention to Response Task

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Précis: Losses of inhibitory control may contribute to some friendly-fire incidents. Small arms simulations were used to test this. Results suggest that environments containing a high proportion of foes may increase the likelihood of friendly fire-incidents, and that speed–accuracy trade-offs occur. Failures of motor inhibition appear to be responsible.

ABSTRACT

Objective

We investigated whether losses of inhibitory control could be responsible for some friendly-fire incidents.

Background

Several factors are commonly cited to explain friendly-fire incidents, but failure of inhibitory control has not yet been explored. The Sustained Attention to Response Task (SART) could be a valid model for inhibition failures in some combat scenarios.

Method

Participants completed small arms simulations using near infrared emitter guns, confronting research assistants acting as friends or foes. In experiment 1, 7 participants completed three conditions with different proportions of foes (high, medium, low). In experiment 2, 13 participants completed high foe (high-go) and low foe (low-go) versions of a small arms simulation as well as comparative computer tasks.

Results

Participants made more friendly-fire errors (errors of commission) when foe proportion was high. A speed–accuracy trade-off was apparent, with participants who were faster to fire on foes also more likely to accidentally shoot friends. When foe proportion was higher, response times to foe stimuli were faster, and subjective workload ratings were higher.

Conclusion

Failures of inhibitory control may be responsible for some friendly-fire incidents and the SART could be a suitable empirical model for some battlefield environments. The effect appears to be disproportionately greater at higher foe proportions. The exact nature of performance reductions associated with high foe proportions requires further investigation.

Application

The SART may be a useful model of friendly-fire scenarios. It could be used to indicate a soldier's likelihood to commit a friendly-fire mistake, and to identify high-risk environments.

Keywords: fratricide, military, blue on blue, response inhibition, motor decoupling, attention, speed–accuracy trade-off

INTRODUCTION

Blue on blue, friendly fire, or the more commonly used colloquial term “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” (Department of the Army, 1992). 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). Friendly fire can occur amongst modern day war fighters for multiple reasons, such as losses of situational awareness, higher fire rates of modern firearms, difficult environmental conditions (e.g., nighttime operations), and cognitive factors. Indeed, with technological advancements fratricide rates have actually steadily increased since the Second World War (Rasmussen, 2007), and friendly fire is estimated to account for between 10 and 24 percent of all allied force casualties (Gadsden, Krause, Dixson, & Lewis, 2008; Schraagen, te Brake, de Leeuw, & Field, 2010). Some research has focused on technological countermeasures, such as the blue force tracking system (Armenis, 2010; Ho, Hollands, Tombu, Ueno, & Lamb, 2013) and rifle-mounted identification friend-or-foe aids. However problems may 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). 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, that is, ground-to-ground. Further contributing to this are a higher proportion of joint operations, increased speed of ground operations, and more frequent urban combat engagements (Hart, 2004). Within the possible solution space of friendly fire, 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 it is not clear whether loss of inhibitory control is a contributing factor in friendly fire incidents (Greitzer & Andrews, 2008). Fast-paced engagements may lead to a potential problem of soldiers being unable to withhold a prepotent fire response. For example, ifsoldiers are engaged in a fire fight in a cluttered environment where the warfighter is confronted by many enemy combatants (targets) embedded within relatively few non-combatants and comrades (e.g., a target-rich environment), soldiers may have difficulty inhibiting their responses to shoot when a comrade or noncombatant appears. Indeed, Helton and colleagues (Helton, Weil, Middlemiss, & Sawers, 2010; Helton & Kemp, 2011) have suggested that this process may already be modeled empirically in the psychological laboratory with the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997).

The SART is a “go/no-go” response task whereby participants respond to numerous go stimuli while withholding to rare no-go stimuli. 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 omission (inappropriately withholding to a Go stimulus), errors of commission (failing to withhold to a No-Go stimulus), and response time to Go stimuli. The primary measures of interest in the SART are errors of commission. 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 (Head & Helton, 2013; Head & Helton, 2014; Helton et al., 2010). When several Go stimuli occur in a rapid sequence the Go motor response becomes prepotent and requires active 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 inappropriate response (error of commission) (Head & Helton, 2012; Head & Helton, 2013; Peebles & Bothell, 2004; Stevenson, Russell, & Helton, 2011). It should also be noted that there is another school of thought on the underlying cause of errors in the SART, known as the mindlessness theory (see Manly, Robertson, Galloway, & Hawkins, 1999; Robertson et al., 1997). This proposes that errors are the result of mind-wandering and perceptual decoupling (failures of sustained attention), rather than losses of motor control or motor decoupling. This idea has largely been discredited however (see Dillard et al., 2014; Head & Helton 2012, 2013; Shaw et al., 2013) and will not be covered here in the interests of brevity.

The SART has 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).

In the current investigation we examine whether the speed-accuracy trade-off process modeled in the SART occurs in a more ecologically realistic small-arms engagement scenario. Unlike previous studies with the SART using computers with simple number or word stimuli, we wanted to see whether the feed forward motor ballistic routine occurs when participants have to physically shoot at foes (Go stimuli) and withhold from shooting friends (No-Go stimuli).

In experiment 1, we investigated whether the SART could indeed provide an empirical model for some battlefield scenarios. Using a relatively realistic paradigm in order to improve ecological validity, we had participants physically search multiple rooms on a floor of a building. Research assistants acting as foes or friends were stationed in different rooms. To explore how different proportions of foes and friends affected error rates we created three conditions which varied in the proportion of foe-to-friendly research assistants: a target rich, high enemy condition (89% foes); a target sparse, low enemy condition (11% foes); and an even enemy-friendly condition (50% foes).

In experiment 2, we used a paradigm where the participant remained stationery for the duration of the experiment. This afforded us greater control, allowing stimuli to be presented at consistent set intervals and enabling us to measure response time on individual trials. The number of participants was greater than in experiment 1, as was the number of trials each participant undertook. Furthermore, we had participants complete comparative computer versions of the Go/No-go tasks.

EXPERIMENT 1

Method

Participants. Eight undergraduate students (five females and 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.

Materials. Participants were instructed to clear rooms on a single floor, by firing at foes but avoiding firing at friends. The participants were armed with a Steradian SX-7 infrared emitter gun (see Figure 1). This was a lazer gun weighing 1.3 kg (2.8 lb) and made primarily of machined metal.

The task utilized several rooms and hallways on a single floor of a building (see Figure 2). Positioned around this floor were 9 research assistants acting as stimuli for the tasks. Research assistants were approximately half males and half females. 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 9 separate zones, which were marked out by chalk on the floor’s carpet. The zones were approximately 5 square meters each and were large enough for the research assistants to move around in with some freedom in order to take a variety of positions.

There were three conditions. One was a high foe condition which was essentially a High Go condition, with 89% of the targets being Go stimuli (foes), just like the computer-based SART and here representing a target-rich environment. A second condition was a low foe condition which was a reversal of the SART condition. Here, 89% of targets were No-Go stimuli (friends). This replicates a Low Go detection task and here represents a target-sparse environment. A third condition had equal probability (50/50) of Go and No-Go stimuli.

The visual cue signaling whether a person 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 color 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 research assistants each possessed a personalized list identifying whether they were to have their hat on or off for each individual trial. This list was created quasirandomly, 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 analyzed to identify when the participants fired their emitter guns.

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.

Figure 1. Steradian SX-7 infrared emitter gun.

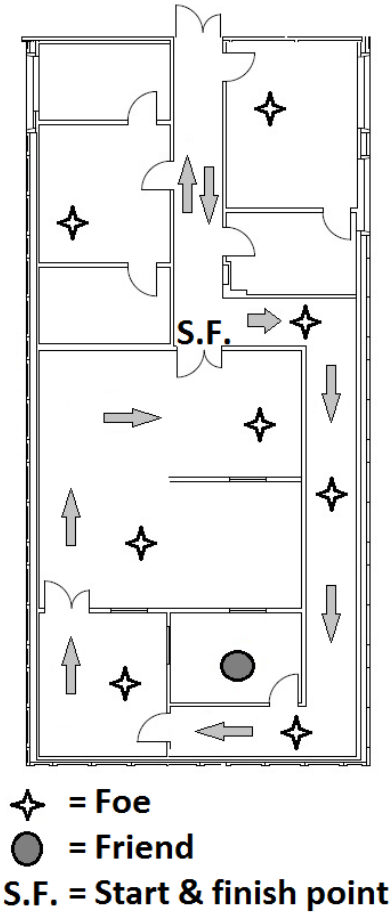

Figure 2. Example floor plan of task area (showing High Go condition).

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 3). The order in which they cleared the 9 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 research assistant 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 the participants himself or herself. They fired regardless of whether they were acting as a friend or a foe stimulus. 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 each time was the visual cue of the hat indicating friend or foe stimuli. Participants received no feedback on their decision after each encounter, e.g., a research assistant 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 beforehand. 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 4 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 research assistants were free to swap zones with other research assistants. Participants completed the workload and task focus scale items immediately after completing each experimental condition, for a total of 3 times. The order in which participants completed the conditions was counter-balanced. No feedback on their performance was given until the end of the experiment. The experiment took approximately 20 min to complete.

Figure 3. Example of a participant clearing an area.

Results

One participant's results were excluded due to failure to comply with task instructions; thus results were analyzed for seven participants. Main effects for condition were tested using one-way repeated-measures ANOVAs and were followed with preplanned 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).

Behavioral measures. For the three conditions, means, standard deviations and effect sizes for the main effects are presented in Table 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-Fedlt correction (Field, 2009). There was a significant main effect for foe proportion on friendly-fire errors (errors of commission), $F(1.09, 6.56) = 6.11$, $p = .04$, $\eta^2_p = .50$. As the proportion of foes increased, the probability of friendly-fire errors also increased. There was a significant quadratic polynomial trend in the relationship, $F(1, 6) = 9.2$, $p = .02$, $\eta^2_p = .61$. A preplanned orthogonal contrast indicated that the high foe (target rich) condition was significantly different to the medium foe and low foe (target sparse) condition, $F(1, 6) = 6.46$, $p = .044$, $\eta^2_p = .519$. There were no omission errors made by any participants in any of the tasks. Due to the nature of the task, we were unable 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, we instead measured the time taken for participants to complete each circuit (course time), which consisted of nine trials, or nine stimuli presentations, each. There were no significant differences for course time over conditions, $F(2, 12) = 1.19$, $p > .05$, $\eta^2_p = .17$. 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, $F(1, 6) = 2.52$, $p = .16$, $\eta^2_p = .30$.

TABLE 1: Behavioral measures: Means and standard deviations for each condition and effect sizes for main effects.

Measure	Low Foe (target-sparse)	Even	High Foe (target-rich)	Effect size (η^2_p)
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
Time (s)	48.0 (12.3)	49.4 (13.0)	51.1 (15.8)	.30

[a]Denotes significant difference between selected condition and the remaining two conditions (preplanned orthogonal contrasts).

*Denotes significance of a main effect at the p < .05 level.

Subjective measures. For the three conditions, means, standard deviations and effect sizes for main effects are presented in Table 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 6 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, $F(2, 10) = 3.98$, $p = .05$, $\eta^2_p = .44$. There was a significant linear trend in this relationship, $F(1, 5) = 6.3$, $p = .05$, $\eta^2_p = .56$. A preplanned orthogonal contrast indicated that the difference between high foe (target rich) and the two other conditions was approaching significance, $F(1, 5) = 6.04$, $p = .06$, $\eta^2_p = .55$.

TABLE 2: Subjective measures: Means and standard deviations for each condition and effect sizes for main effects.

Measure	Low Foe (target sparse)	Even	High Foe (target rich)	Effect size (η^2_p)
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) ^{c}	.44

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

Discussion

Participants cleared the floor of a building, firing at research assistants representing foes and withholding fire to research assistants 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.

EXPERIMENT 2

In Experiment 1, we investigated whether the SART could be used to model friendly-fire incidents by using a small-arms simulation with a higher degree of ecological validity than is seen in much SART research. Our results suggested that behavior in some battlefield scenarios could be similar to that typically observed in the SART. Namely, as the required shoot (response) proportion became higher, participants' ability to hold fire (withhold responses) became poorer. However we were unable to reliably gauge participants' response times, an important SART metric. Furthermore, only a small number of participants were recruited which may have led to some results being understated. Therefore in experiment 2, we used a slightly different paradigm which gave us tighter experimental control and allowed response times for each individual trial to be measured. A larger number of participants was recruited and each participant completed a greater number of trials. Participants also completed computer versions of the Go/No-Go tasks, which had identical Go/No-Go proportions to the firearm tasks.

Method

Participants. Thirteen undergraduate students (seven males andsix females) 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 and were compensated with NZD$20 vouchers. This sum of monetary compensation was chosen because unlike in Experiment one, an opportunity for compensating participants with course credit did not arise. This sum was believed to be of a comparable value to the course credit offered in experiment one.

Materials. There were two different foe/Go versus friend/No-Go stimuli relative probabilities for the task, the SART (high foe/High Go) and a SART-reversal task (low foe/Low Go), where the relative proportion of Go and No-Go responses is inverted, which is identical to the Traditionally Formatted Task (TFT; see Helton, 2009). There were also two different scenarios of the two tasks (small arms simulation with live humans; and computer task with number stimuli). There were thus four tasks in total. Participants completed all four tasks: a computer SART, a computer SART reversal, a firearm SART, and a firearm SART reversal. As with experiment one, the SARTs could be thought of as target-rich scenarios and the SART-reversals 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 told to respond as quickly and accurately as possible for all tasks. Stimuli presentation and recordings of response times and accuracy were performed by personal computers running E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). 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 4). 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.

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. This was for the purpose of keeping the actual physical response as consistent as possible with the firearm 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 5). The computer tasks were not characterized to participants in any particular way, such as an operational scenario.

For the SART, participants were to respond to frequently occurring Go stimuli and withhold to No-Go stimuli. Go stimuli probability was .89 and No-Go stimuli probability was .11. The SART reversal or target sparse scenario was perceptually identical to the SART except Go stimuli occurred with a probability of .11, and No-Go stimuli more frequently with a probability of .89. In the SART the Go stimuli were the numbers 1-9, excluding the number 3 which served as the No-Go stimulus. This was the opposite for the SART reversal, where the number 3 was the Go stimulus and the numbers 1-9 (excluding 3) were the No-Go stimuli. The SART and SART reversal were each 4.3 min in duration and consisted of 225 trials. Number stimuli were all of Arial font but varied in size randomly. The font sizes were 48, 72, 94, 100, and 120, with height varying between 12 and 29 mm.

Firearm tasks. The firearm tasks involved the participant being stationed in a hallway, standing or leaning at a "leaner" structure 1,240 mm high. The leaner had a flat top/surface on which a pillow was placed which gave a similar feel to a sandbag as well as helping 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 research assistant, 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 research assistant did not appear first during trials. Participants wore earmuffs so that they could not hear any of the movements of the research assistant which could have provided them with a cue for stimulus onset. For consistency purposes they also wore these in the computer tasks. The black balaclava was worn so that participants were not distracted by visual cues from facial expressions. This also forced them 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 another 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 research assistant was out of view of the participant, was when the other research assistant was able to quickly turn the cap around when required, out of sight of the participant.

There were 180 trials for each of the gun tasks. Due to the physically demanding nature of the task (with a real person moving), trials took 4 sec each. The total time for each task was 12 min. As with the comparative computer tasks, in the firearm SART there was a probability of .11 for a friend (No-Go stimulus) to appear, and a probability of .89 for a foe (Go stimulus) to appear. For the firearm SART-reversal this probability was reversed.

Figure 4. Modified Steradian SX-7 infrared emitter gun containing added micro switch (see below the grip).

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 experiment one. 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.

Procedure. Participants surrendered their wristwatches and cell phones upon reporting for the study, and all were tested individually. Before each task participants were given a short practice (18 trials) in order to familiarize them with the task. This was not used to remove any participants based on performance. Participants completed all four tasks (computer SART, computer SART-reversal, firearm SART, and firearm SART-reversal). The order of the tasks was counterbalanced in a nested design: approximately half of participants (7) did the firearm tasks first, and the remainder (6) did the computer tasks first. Within these, approximately half completed the SART response paradigm first and the remainder completed the SART-reversal response paradigm 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 numbers 1-9 (inclusive) was visually presented on the computer screen for 250 ms. 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 (see Figure 5).

Firearm tasks. Participants were instructed that they would be trying to shoot a person (research assistant) appearing intermittently in a doorway. Some of the time the person would be a friendly, as in someone on their side or team, and other times the person would be an enemy, from an opposing force. This was to be signaled by the direction of the cap which the person was wearing. The person was also armed with an SX-7 gun, and participants were told the 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 (see Figure 6). 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. The balaclava-clad research assistant would be visible in the doorway for approximately 1.5 sec. In order for this to be consistent, a 1.5-s burst of white noise (75 dBA) was played over earphones worn by the research assistant. The beginning of the sound burst signaled the research assistant to step into the doorway and the end of the noise burst signaled the research assistant to step out of the doorway. The research assistant was careful to move out in the same manner each trial. 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 research assistant's need to move into view. The research assistant behaved in the same manner following a participant's shot or no-shot regardless of whether they were acting as a friend or foe.

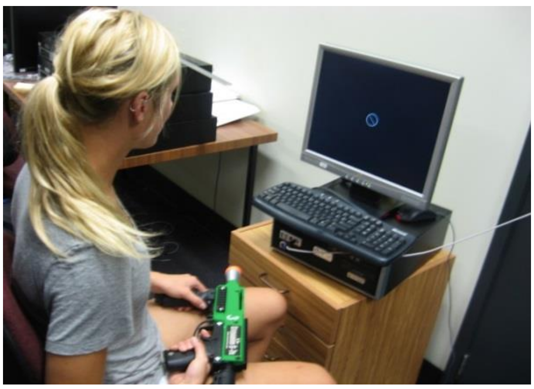

Figure 5. Example of the computer task setup.

Figure 6. Example of the firearm task setup.

Results

Behavioral measures. The means and standard deviations for each condition are presented in Table 3. To explore the differences between conditions we used 2 (task method: computer vs. gun) x 2 (response paradigm: SART vs. SART-reversal) repeated measures ANOVAs. For friendly fire errors or errors of commission, there was a significant main effect for response paradigm, $F(1, 12) = 170.18$, $p < .001$, $\eta^2_p = .934$. There was also a significant main effect for task method, $F(1, 12) = 9.62$, $p = .009$, $\eta^2_p = .445$. Furthermore, there was a significant interaction effect for task method with response paradigm $F(1, 12) = 11.71$, $p = .005$, $\eta^2_p = .494$. Commission errors were higher in the SART paradigm than the SART-reversal paradigm and higher in the computer version than the firearm version. The magnitude of the difference between the two response paradigms was larger in the computer version than the firearm version. For failures to fire or errors of omission, there was a significant main effect for task method, $F(1, 12) = 10.71$, $p = .008$, $\eta^2_p = .459$. More omission errors were made in the firearm version than the computer version. There was no significant main effect for response paradigm, $F(1, 12) = .723$, $p = .412$, $\eta^2_p = .057$, nor was there a significant interaction effect between task method and response paradigm $F(1, 12) = 3.84$, $p = .074$, $\eta^2_p = .242$. For response time, there was a significant main effect for task method, $F(1, 12) = 2643.00$, $p < .001$, $\eta^2_p = .995$, and of response paradigm, $F(1, 12) = 75.34$, $p < .001$, $\eta^2_p = .863$. There was also a significant interaction between task method and response time, $F(1, 12) = 11.87$, $p = .005$, $\eta^2_p = .497$. Response times were faster in the SART paradigm than the SART-reversal paradigm and faster in the computer version than the firearm version. The magnitude of the difference between the two response paradigms was larger in the computer version than the firearm version, as it was with commission errors. Pairwise comparisons were then performed to further investigate the differences between the SARTs and the SART-reversals. The results of these, specifically the effect sizes (unstandardized mean differences) with 95% confidence intervals, are displayed in Table 3 (see Cumming, 2014).

TABLE 3: Behavioral Metrics: Means and Standard Deviations for Each Condition, Mean Differences, and 95% Confidence Intervals

Measure	SART (target-rich)	SART-reversal (target-sparse)	Mean difference	Lower 95% C.I.	Upper 95% C.I.
Firearm					
Friendly fire/Errors of commission (%)	32.7 (16.8)	1.2 (2.2)	31.5	21.3	41.7
Failure to fire/Errors of omission (%)	.6 (.8)	1.2 (1.1)	-.6	-1.5	.3
Response time (ms)	1111 (63.0)	1248 (63.6)	-173.1	-101.2	-173.1
Computer					
Friendly fire/Errors of commission (%)	55.4 (17.7)	.3 (1.1)	55.1	44.4	65.7
Failure to fire/Errors of omission (%)	.4 (.5)	.2 (.3)	.2	-.1	.5
Response time (ms)	324 (50.9)	398 (32.8)	-72.9	-103.3	-42.6

Note. SART = Sustained Attention to Response Task; CI = confidence interval.

Subjective measures. The means and standard deviations for each condition are presented in Table 4. Like the behavioral results, 2 (task method: computer vs. firearm) x 2 (response paradigm: SART vs. SART-reversal) repeated measures ANOVAs were used to detect any differences between conditions. For the global workload measure, there was a significant main effect for response paradigm, $F(1, 12) = 14.70$, p .002, $\eta^2_p = .551$. There was no significant main effect for task method, $F(1, 12) = 1.97$, $p = .185$, $\eta^2_p = .141$, however there was a significant interaction between task method and response paradigm, $F(1, 12) = 6.33$, $p = .027$, $\eta^2_p = .345$. Global workload was higher in the SART paradigm than the SART-reversal paradigm, and the difference between the two paradigms was more pronounced in the computer version than in the firearm version. Individual subscale items were then analyzed. Mental demand was significantly higher for the SART than the SART-reversal, $F(1, 12) = 7.74$, $p = .017$, $\eta^2_p = .127$. Physical demand was significantly higher for the SART than the SART-reversal, $F(1, 12) = 5.13$, $p = .043$, $\eta^2_p = .299$, and also higher for the firearm version than the computer version, $F(1, 12) = 13.25$, $p = .003$, $\eta^2_p = .525$. Temporal demand was significantly higher for the SART than the SART-reversal, $F(1, 12) = 6.35$, $p = .027$, $\eta^2_p = .346$. Finally, effort was significantly higher for the SART than the SART-reversal, $F(1, 12) = 10.32$, $p = .007$, $\eta^2_p = .462$. 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 SARTs and the SART-reversals. The results of these, specifically the effect sizes (unstandardized mean differences) with 95% confidence intervals, are displayed in Table 4 (see Cumming, 2014).

TABLE 4: Subjective metrics: Means and standard deviations for each condition, mean differences and lower and upper 95% confidence intervals.

Measure	SART (target-rich)	SART-reversal (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	.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)	-.8	-11.4	13.0
Effort	77.7 (22.6)	69.6 (25.0)	8.1	.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.

Relationship between response time and friendly fire errors. Correlations between response times and errors of friendly fire/commission were analyzed using standardized *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 7), for both the computer task, $r(11) = -.78$, $p < .05$, and the firearm task, $r(11) = -.64$, $p < .05$.

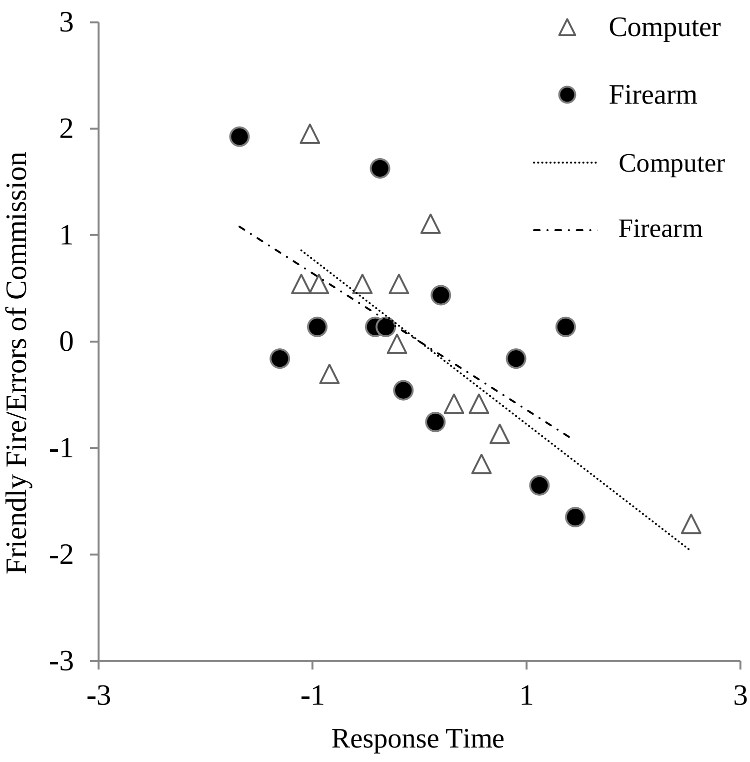

Figure 7. *Correlations between friendly fire/errors of commission and response time for both the firearm task and the computer task using z score transformations.*

Discussion

Participants completed both a computer and a simulated small-arms scenario, in both a SART (target rich; High Go) and SART-reversal (target sparse; Low Go) condition. Errors of friendly fire or commission errors were higher and response times were faster in the SART conditions compared to their SART-reversal counterparts. Both the computer and small arms scenario revealed similar speed-accuracy trade-offs; faster response times were associated with increased errors of friendly fire/commission. Subjective reports of workload were higher in the SARTs than the SART-reversals.

GENERAL DISCUSSION

In the present study we used friend-or-foe (No-Go/Go) tasks in simulated small-arms engagements and comparative computer tasks to determine whether the speed-accuracy process of the SART might be relevant in some settings where friendly fire could occur. We further performed the same types of tasks in two lower foe (lower Go) versions for comparison, specifically the SART-reversal (see the TFT; Helton, 2009) and a mixed 50/50 task. Subjective workload was measured with the NASA-TLX after all tasks. In experiment 1, the small-arms simulation required participants to physically move around a floor of a building, firing at foes and withholding to friends over three conditions containing different proportions of enemies: high-foe (target rich), medium-foe, and low-foe (target sparse). In experiment 2, participants remained stationery and were confronted with enemy and friendly stimuli in a more systematic procedure. They completed both the SART and the SART-reversal within the small-arms simulation and additionally within comparative computer versions of the tasks.

Participants made significantly more friendly fire errors or commission errors when the Go (foe) proportion was higher. A polynomial contrast performed in experiment 1 revealed a significant quadratic relationship here. There was strong evidence of speed-accuracy trade-offs in experiment 2, with those participants responding faster in the SART (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 in experiment 2. The global workload ratings in experiment 2 were higher for the SART version than the SART-reversal version 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 SART paradigm than the target sparse SART-reversal paradigm. While no significant differences were found in the global workload ratings from experiment 1, a measure of task focus was found to increase as the proportion of foes increased.

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, Russell, & Helton, 2013; Head & Helton, 2012; Stevenson, Russell, Helton, 2011). The greater amount of firing appears to have caused a prepotent motor response routine to develop, thus making it difficult for participants to withhold fire to the rarely-occurring friends. Interestingly, this effect appeared to occur in an exponential rather than a linear fashion, 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 of sorts, where the foe proportion surpasses a certain level and a prepotent motor ballistic routine develops causing performance to decline. If so, this threshold appears to be somewhere between the 50% and 89% foe/Go proportion, that is, a target-rich environment. Authors of future research should more closely examine the functional relationship between friend-foe probability and friendly fire.

Although speed-accuracy trade-offs were substantial in both the firearm and computer versions of the SART within experiment 2, the relationship was slightly weaker in the firearm version. This was presumably due to either less accuracy in measuring response time (as the movement of the research assistant could not be perfectly kept 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, 2009; Peebles & Bothell, 2004).

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, e.g., “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, 2011). That the differences observed in omission errors here were between the firearm and computer tasks, suggests that 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. This idea could possibly be challenged by the finding that no omission errors at all were made in experiment one where all tasks involved a firearm. However, perhaps the reason participants successfully fired at 100% of foe targets in the experiment one tasks was that the nature of these trials allowed them more time to fire a shot. There may have been cases where they had initially withheld fire, but then (after a short but significant period of time) realized the research assistant was a foe and consequently fired. Conversely, in experiment two trials the research assistant was only visible to the participant for a brief set period of time, so if they had initially (incorrectly) held fire they probably did not have time to reverse their decision before the research assistant had disappeared out of view again.

The findings that the global workload measure and all four of its subscale items (experiment two), as well as the task focus measure (experiment one) were higher in the SART 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, e.g., the SART-reversal and the target sparse scenarios. Task focus scores were the highest for the high foe condition, the condition which 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, Russell, & Helton, 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 mistakes. The participants were aware of the challenge posed by High Go probability. In general, scores for global workload and task focus were quite high, suggesting that participants took their assignment seriously.

While there were no significant differences within the chosen time measure over conditions in experiment 1, 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 insignificance. 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. When the movement or response time was not self-paced but externally paced (as in experiment 2), high foe probabilities or target rich environments resulted in quicker response times and subsequently more friendly fire errors.

The limitations of the modified NASA-TLX used here should be noted. 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. Secondly, there may be concerns about whether the findings of Bailey and Thompson (2001) and Ramiro et al. (2010) are robust enough to warrant modification of the NASA-TLX. 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.

Due to the intricate and time-consuming nature of the task in experiment 1, only 8 participants were recruited, and only data from 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 research assistants means this kind of research with live actors is resource challenging. The use of virtual environments is one possible solution to this (e.g., Bryant & Smith, 2009; Patton, 2014). Despite the small sample size in experiment one, effect sizes were relatively large, supporting the interpretation of the reported findings. Indeed, effect sizes were similarly large in experiment two and an improved sample size coincided with more significant results. 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 more ecologically valid scenario as well. It suggests that the feed forward ballistic routine may occur in some battlefield scenarios where soldiers are demonstrating typical SART-like responding, by responding to frequently occurring “target stimuli” (foes) and only rarely needing to withhold to infrequently occurring “neutral stimuli” (comrades or civilians).

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) utilized 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).

Authors of future research should 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 ratio 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 unraveling the cause of the functional relationship itself. Other researchers should also look to use professional soldiers in their research, as there could be differences in the nature of their performance relative to the unskilled civilians utilized 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 & Helton (2014) found that participants made more errors of commission after practice on a SART. Certainly, another question is how target identification training influences motor inhibition.

These findings may have implications for firearm scenarios. It appears that the prepotent motor response in a High Go/Low No-Go task (e.g., a target-rich environment) is difficult to inhibit. 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 prepotent action. Even when the target is very easy to perceptually discriminate, if fast responses are demanded by the situation, the individual may still fire on non-foes. 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. This could perhaps also include civilian hunting accidents and law enforcement.

Key points:

- Failures of motor inhibitory control may be responsible for some friendly fire incidents.
- The SART may be useful as an empirical model for friendly fire scenarios.
- The likelihood of motor inhibition failures, and thus friendly fire incidents, appears to be disproportionately greater at higher foe proportions, e.g., target rich environments.
- The exact nature of performance reductions warrants further investigation.

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