Real Life Does Not Always Get in the Way: Verbal Memory and the Sustained Attention to Response Task

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ABSTRACT

The Sustained Attention to Response Task (SART) is a go/no-go task where participants must respond frequently to target stimuli and withhold responses from infrequent neutral stimuli. Researchers have shown that the fast and frequent responding characteristic of SART is typically associated with difficulty withholding responses to no-go stimuli. Imposing additional cognitive demands has been shown to further impair task performance. In the present research, participants completed a modified SART task, a narrative memory task, and a dual-task condition where both were done simultaneously. No significant performance impairments were found in the dual- compared to single-task conditions. The tasks' non-overlapping resource demands, alongside a potential arousing benefit of the memory task, may explain the lack of notable dualtask interference. Future research is needed to better understand the effects of arousal and other factors that may help to uncouple errors of commission from response time, particularly in tasks with high ecological validity.

The ability to manage multiple cognitive (and sometimes physical) demands is required of operators in many high-risk domains. Pilots monitor a vast instrument panel while also flying the plane and communicating with air traffic control; search and rescue teams traverse treacherous terrain while navigating unknown routes and communicating with teammates or remote intelligence sources; emergency responders may make complex treatment decisions and execute those decisions while simultaneously helping with evacuation. In many cases, the division of attention, alongside limits on cognitive processing capacity, can lead to mistakes.

Friendly fire may be one such mistake. 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 is said to occur for reasons such as loss of situation awareness, suboptimal environmental conditions, and other cognitive factors (Wilson, Head, de Joux, Finkbeiner, & Helton, 2015). Recent research has focused on better understanding the effects of new weapons with high rates of fire, competing cognitive demands, and loss of inhibitory control on friendly fire outcomes (Munnik, Naswall, Woodward, & Helton, 2020; Wilson et al., 2015; Wilson, Head, & Helton, 2013; Wilson, Finkbeiner, de Joux, Head, & Helton, 2014). Rather than perceptual failures (i.e., failing to visually distinguish friend from foe), these researchers have proposed that errors may arise from response strategy. Frequent responding may lead to a feed-forward ballistic motor program which becomes difficult to inhibit, particularly when operators must respond as quickly as possible – i.e., shoot before being shot (Head & Helton 2013; 2014; Helton 2009; Helton, Head, & Russell, 2011; Helton, Kern, & Walker, 2009; Helton, Weil, Middlemiss, & Sawers, 2010; Wilson et al., 2015).

In addition to the effects of the impulsive motor program on response accuracy, it is also important to understand the effect of additional cognitive load when undertaking such tasks. Munnik and colleagues (2020) recently found that response times were faster in a shoot/no-shoot simulation task performed on its own than when performed simultaneously with a verbal memory task, but errors of commission (EC; responding to “no-go” or neutral stimuli) did not differ between single- and dual-task conditions. However, errors of omission (EO; failing to respond to “go” or critical stimuli) were greater in the dual- compared to single-task condition. In other words, additional cognitive load did not lead to more false alarms (i.e., friendly fire), but did lead to a decreased ability to shoot critical targets – which is also a safety concern.

The Sustained Attention to Response Task (SART) is a go/no-go task that requires inhibition of impulsive responding, and has thus been used as a paradigm for studying friendly fire. SART requires operators to respond as quickly as possible to frequent go stimuli (i.e., foes), and withhold responses from infrequent, no-go stimuli (i.e., friendlies). Performance in such tasks is often characterized by a speeding up of responses over time, accompanied by an increase in EC (Funke et al. 2012; Dillard et al. 2014; Wilson, Finkbeiner, de Joux, Russell, & Helton, 2016). In contrast to the findings of Munnik and colleagues (2020), Head and Helton (2014) found that when paired with the same verbal memory task, EC in a SART task significantly increased in the dual- compared to single-task condition, but they failed to find a significant difference in response time. However, similar to Munnik and colleagues, Head and Helton found significantly fewer EO in the single-task as opposed to the memory load condition.

It is worth noting that the verbal memory task used in both studies above required participants listen to and later freely recall a list of discrete, unrelated words, which has minimal ecological validity. In response to a similar problem in their own research, Epling and colleagues developed a narrative memory task, said to be more applicable to real world demands (Epling, Blakely, Edgar, Russell, & Helton 2018; Epling, Edgar, Russell, & Helton 2018; 2019). Unlike a free recall task, understanding verbal cues from an individual's surroundings or remembering the gist of a conversation could be very important in real-world situations (Epling, Blakely, et al., 2018): poor comprehension or failed memory of a situation or conversation can lead to accidents or mistakes (Edgar & Edgar 2007).

Thus, the present research utilized a dual-task paradigm where participants completed a modified SART task, the narrative memory task described above, as well as a dual-task condition where both tasks were completed simultaneously. Due to increased cognitive resource demand in the dual-task condition and outcomes of prior SART research (Head & Helton, 2014; Kahneman, 1973; Wickens, 2002; 2008), we hypothesized that both EC and EO would be greater in the dual- compared to single-task conditions. Additionally, we hypothesized that performance on the memory task would also be better in the memory single- compared to dual-task condition. Finally, we predicted that EC would be negatively associated with response time, consistent with the motor response-performance association illustrated in prior research (Head & Helton 2014; Wilson et al., 2015). Participants were also required to report subjective workload after each task condition, and we expected the dual-task to impose greater subjective workload than either task individually.

METHOD

Participants

Thirty-five undergraduate psychology students (25 women) at the University of Canterbury served as participants for course credit. All participants had normal or corrected-to normal vision, normal hearing, and were fluent in English. Age of participants ranged from 18 to 52 years (M = 24 years, SD

= 8.71). The study was approved by the University Human Ethics Committee, and informed consent was gained from each participant.

Design

This experiment utilized a repeated measures design, with participants completing all three conditions. Condition A was the narrative memory single-task, Condition B was the SART single-task, and Condition C was the dual-task (SART task + narrative memory task). There were two different audio scenarios created for the narrative memory task so that participants would hear one in Condition A, and the other in Condition C. Participants were randomly assigned to one of six groups, which counterbalanced the order of the three conditions and the two memory scenarios.

Materials

Narrative Memory Task.

Two audio scenarios, presenting a simulation of people involved in a building fire, were designed to be audio equivalents of visual scenarios that were successfully developed and tested for prior situation awareness research (Catherwood, Edgar, & Sallis, 2012). Audio tracks were each five minutes in length, and had 24 associated true/false probe statements to test participants' memory (for details, see Epling et al., 2019). To listen to scenarios, participants wore over the ear headphones throughout the experiment.

SART task.

The modified SART task used in this experiment displayed the numbers 1 - 9 in one of three positions on a computer screen. The keyboard spacebar was used to respond to all go items (all numbers but 3), which always appeared in the center of the screen. The no-go item (3) always appeared either to the right or left of center. All of the numbers were in black Courier New font and could appear in five different sizes ranging from 48 to 120. Stimulus presentations and recordings of response times and accuracy were executed by PC computers with E-Prime Professional 2.0 (Schneider, Eschman, & Zuccolotto, 2002). Stimuli appeared for 250ms, followed by a 900ms mask, for a total answer period of 1150ms. The stimuli were programmed in blocks of 51.75 seconds, each block randomly presenting five no-go and 40 go stimuli. The program looped through six blocks for a total trial time of five minutes and 10 seconds. Because Conditions A and C have an audio component (the narrative memory scenario), a scrambled audio scenario was played during the SART-alone task (Condition B). The scenario was incomprehensible and participants were told that there would not be a memory test.

Questionnaire.

A paper version of the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988) was used to collect participants' subjective workload in each task. The NASA-TLX is considered an effective measure of perceived workload (Funke et al., 2016) on a scale of 0-100 based on the average of six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration.

Procedure

Participants were tested at cubicle computer workstations in a laboratory at the University of Canterbury. Participants were unrestrained and seated approximately 50cm from eyelevel screens (377 x 303 mm, 60 Hz refresh rate). Participants were asked to adjust volume to a comfortable level before beginning, and to put away cell phones and watches.

Upon launching the program, participants were prompted to enter biographical data and then progress through instruction slides regarding the three task conditions.

For Condition A (narrative memory), participants were told computer screens would remain blank, and to listen to the scenario and remember it to the best of their ability. When the audio track finished, participants were instructed to complete the response sheet, marking each statement as true or false. For Condition B (SART), participants were instructed to monitor the screen and press the space bar in response to all numbers except for the number 3, as quickly and accurately as possible. Participants were told there would be no memory test for the jumbled audio track that would play during this task. For Condition C (dual-task), participants were told to perform the SART task while simultaneously listening to the memory scenario, after which they would fill out the response sheet. For Condition C, the memory scenario commenced 10 seconds after the SART task began, so the time between the end of the recording and beginning the memory test would be consistent between the single- and dual-tasks.

After the initial instructions, participants were then given a brief practice session on the SART task, in which they saw 16 stimuli at speed and were given audio hit or miss feedback in real time. They were then asked if they had any questions. When comfortable with instructions, participants advanced to the experimental tasks. The instructions for each task condition were shown again as they arose in the sequence of events. Upon completing each task condition, participants were instructed to fill out the NASA-TLX before advancing to the next task condition.

RESULTS

Narrative Memory

Each memory questionnaire had 24 true/false probes. Participants were also asked to rank each of their responses as a guess, fairly uncertain, fairly certain, or certain (scored 1-4 respectively). For each participant we scored the number correct responses (CR), and also calculated the proportion of hits (H; marking a true statement as true) and false alarms (FA; marking a false statement as true) for each task condition. We then calculated the signal detection theory metrics of A´ (sensitivity) and B´´ (bias) from these proportions using the process described by Edgar, Edgar, and Curry (2003). We also calculated the average confidence for each participant in each task.

There was no significant difference in the number of CR in the memory task between the single- (M = 18.1, SD = 2.59) and dual-task (M = 17.2, SD = .07), t(35)= 1.692, p = .100, $M_{difference}$ = .861 (95% CI [-.172,1.894], or in the proportion of H between single- (M = .81, SD = .15) and dual-task (M = .79, SD = .15), t(35) = .552, p = .585, $M_{difference}$ = .01 (95% CI [- .03,.06]. The difference in the proportion of FA between single- (M = .29, SD = .14) and dual-task (M = .34, SD = .16) was also nonsignificant, t(35) = 1.67, p = .104, $M_{difference}$ = .05 (95% CI [-.02,.11]).

For A´, the difference in sensitivity between single- (M = .834, SD = .104) and dual-task condition (M = .799, SD = .145) was nonsignificant, t(34) = 1.525, p = .136, $M_{difference}$ = .036 (95% CI [-.012,.083]. There was also a nonsignificant difference in B´´ between single- (M = -.172, SD = .287) and dual-tasks (M = -.191, SD = .246), t(35) = .352, p = .727, $M_{difference}$ = .015 (95% CI [-.097,.127]. Participants were, however, significantly less confident about their responses in the dual- (M = 2.89, SD = .469) compared to single-task (M = 3.06, SD = .450), t(34) = 2.33, p = .026, $M_{difference}$ = .175 (95% CI [.022,.328]).

SART

We collapsed the SART data into three 103.5 second periods, each including 80 go and 10 no-go stimuli. For each participant, we calculated the proportion of EO (out of 80) and EC (out of 10) in each of the three periods for the single- and dual-task. We then ran a 3 (period) by 2 (single- vs. dual-task) repeated measures analysis of variance (ANOVA). For these tests, we used orthogonal polynomial contrasts because they are powerful tests for looking at changes over time, without a concern with violation of the sphericity assumption.

There was no significant difference in EO between the single- (M = .006, SE = .001) and dual-task condition (M = .007, SE = .002), $F(1,34) = .257$, $p = .616$, $\eta_p^2 = .007$. The linear trend for period was statistically significant, $F(1,34) = 8.90$, $p = .005$, $\eta_p^2 = .207$. Mean EO increased from 0.3% to 0.8% across periods, as seen in Figure 1. The linear trend for the task by period interaction was nonsignificant, $F(1,34) = 2.06$, $p = .160$, $\eta_p^2 = .057$.

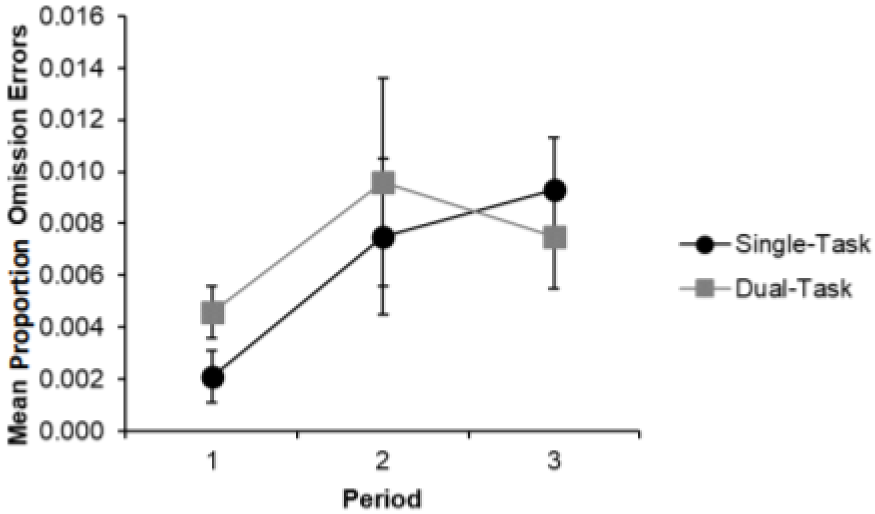

Figure 1 Mean proportion EO across periods in single- and dual-task conditions. Error bars are standard error of the mean.

The difference in EC between single- (M = .151, SE = .012) and dual-task conditions (M = .180, SE = .022), was also nonsignificant $F(1,34) = 2.6$, $p = .116$, $\eta_p^2 = .071$. The linear trend for period was nonsignificant, $F(1,34) = 1.47$, $p = .233$, $\eta_p^2 = .042$, but the linear trend for task by period interaction was significant, $F(1,34) = 11.77$, $p = .002$, $\eta_p^2 = .257$. The mean proportion of EC across periods is shown in Figure 2.

The mean response time of correct responses to go stimuli did not significantly differ between the single- and dual-task conditions, $F(1,34) = 1.45$ $p = .237$, $\eta_p^2 = .041$. However, there was a significant linear trend for period, $F(1,34) = 70.52$, $p < .001$, $\eta_p^2 = .675$, as well as a significant quadratic trend for period, $F(1,34) = 13.98$, $p = .001$, $\eta_p^2 = .291$. Speed of response decreased from an average of 334ms in period one to 296ms in period three, as seen in Figure 3. The linear trend for the task by period interaction was nonsignificant, $F(1,34) = .002$, $p = .968$, $\eta_p^2 = .000$. There was not a significant

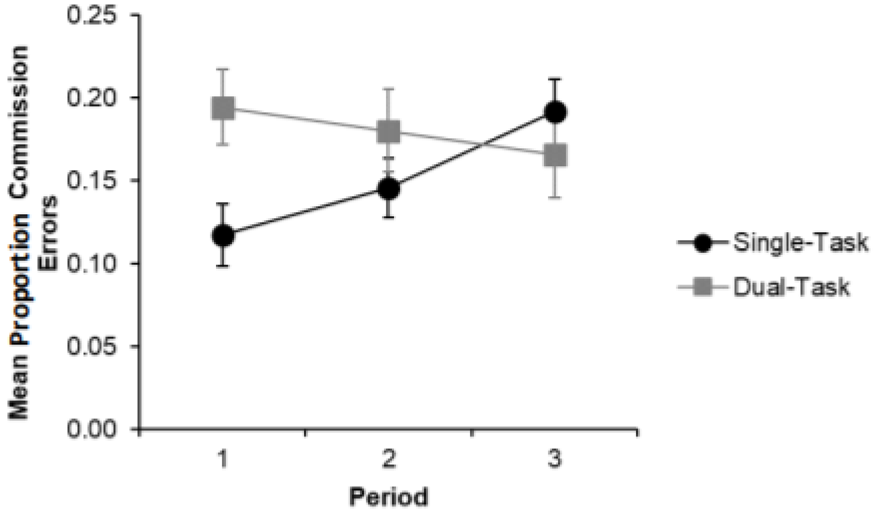

Figure 2 Mean proportion of EC across periods in single- and dual-task conditions. Error bars are standard error of the mean.

correlation found between error rates and response times in either the single- or dual-task conditions.

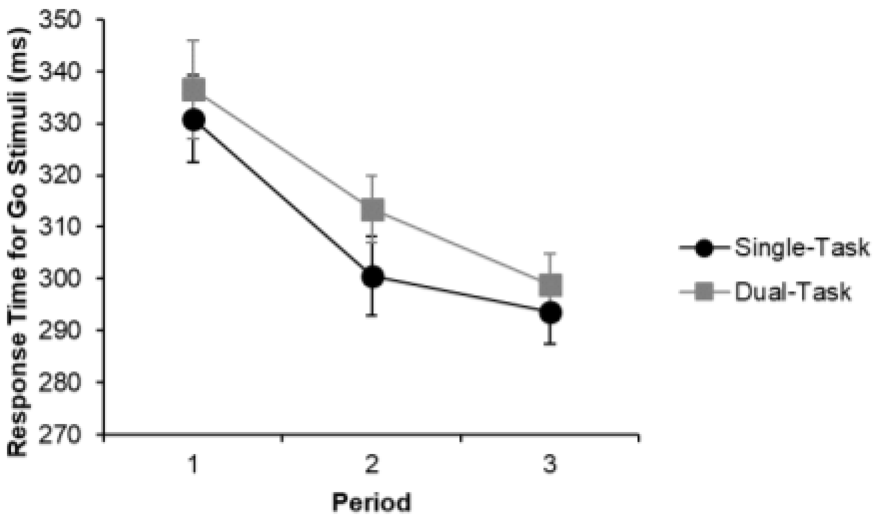

Figure 3 Mean go stimuli response time (ms) for both tasks across periods. Error bars are standard error of the mean.

Subjective Workload

The mean rating on each subscale of the NASA-TLX, on a scale of 0-100, is shown in Table 1. The average workload component is the mean of the six subscales.

Table 1 Self-report average on the TLX subscales.

	Memory	Dual-Task	SART
Mental Demand	51.1 (3.9)	74.9 (2.3)	66.1 (3.7)
Physical Demand	12.0 (2.5)	25.1 (3.8)	26.7 (4.0)
Temporal Demand	39.6 (4.0)	70.0 (2.9)	67.6 (3.5)
Performance	39.1 (3.2)	43.4 (2.7)	44.4 (3.8)
Effort	53.4 (3.7)	72.1 (2.4)	66.4 (3.4)
Frustration	32.9 (4.2)	45.6 (4.5)	57.0 (5.2)
Average	38.0 (2.5)	55.2 (2.0)	54.7 (2.8)

Note. Each value is the mean (standard error of the mean) self-report rating across all participants for that measure.

Planned comparisons revealed that dual-task mean workload ($M = 55.19$, $SD = 11.61$) was not significantly different than SART-alone workload ($M = 54.71$, $SD = 16.31$), $t(34) = .195$, $p = .846$, $M_{difference} = .48$ (95% CI [-.4.48,5.43], but was significantly greater than memory task alone workload ($M = 38.02$, $SD = 14.84$), $t(34) = 7.958$, $p < .001$, $M_{difference} = 17.17$ (95% CI [12.78,21.55]). The SART-alone workload was also significantly greater than the memory-alone workload $t(34) = 9.278$, $p < .001$, $M_{difference} = 16.69$ (95% CI [13.03,20.35]).

Though not hypothesis-driven, interesting subscale mean values led to two additional exploratory comparisons. Mental demand was found to be significantly higher in the dual-task condition ($M = 74.9$, $SD = 13.4$) than the SART-alone condition ($M = 66.1$, $SD = 21.9$), $t(34) = 2.53$, $p = .016$, $M_{difference} = 8.7$ (95% CI [1.7,15.7]), though frustration was significantly higher in the SART-alone ($M = 57.0$, $SD = 30.9$) compared to dual-task condition ($M = 45.6$, $SD = 30.9$), $t(34) = 2.74$, $p = .010$, $M_{difference} = 11.4$ (95% CI [2.9,19.9]).

DISCUSSION

While participants had lower confidence in their memory performance and reported higher workload in the dual-compared to single- memory task, actual memory and SART performance did not significantly differ between single- and dual-task conditions. This, along with a lack of correlation between response times and error rates, indicate a lack of support for the hypotheses.

Though it was predicted that a reduction in both memory and SART performance would occur in the dual-task, it has been suggested that the present narrative memory task demands less executive-controlled, effortful processing than the free recall task used by Head and Helton (2014), which typically involves rote rehearsal as a memory strategy (Epling, Blakely, et al., 2018). Additionally, there is minimal to no overlap in specific resource demands along the dimensions proposed by Wickens' Multiple Resource Theory (MRT; 2002; 2008): the memory task utilized primarily audio and verbal processing, while SART is a visual-spatial task. Finally, our modified SART task always displayed the go stimuli in the center of the screen, while the no-go stimuli always appeared to the left or right of center – making this a relatively easy version of the task. The consistent location cue allows for a faster decision on whether the stimulus is a go or no-go, allowing the pre-potent response to be halted more quickly and ECs more easily avoided than versions of SART where stimulus location is not deterministic. Recent research utilizing the same version of SART also found that despite fast response times, there were few errors (Bedi, 2018).

An alternate possibility for why SART task performance was not impaired by extra cognitive load is that anxiety or arousal (induced by increasing the cognitive load without surpassing available capacity, and/or the intense nature of the fireground scenarios) may improve response inhibition (Robinson, Krimsky, & Grillon, 2013; Wilson et al., 2015). Because the dual-task requires more cognitive processing than either task alone, and also presents a narrative about a stressful situation, the dual-task condition may increase anxiety or arousal and thus improve one's ability to inhibit inappropriate responses. Kahneman (1973) cites arousal as a key factor in the ability to mobilize mental resources: on simple tasks, people may not be able to perform their best if under-aroused. Similarly, the Yerkes-Dodson Law (Yerkes & Dodson, 1908) states that performance is optimal at an intermediate level of arousal, and optimal performance on a simple task requires more arousal than on a complex task (Bahrick, Fitts, & Rankin, 1952). Thus, a dual-task performance impairment (as hypothesized) and arousal-based performance benefit could have cancelled each other out, leading to the nonsignificant differences in performance measures between single- and dual-task conditions.

Though the difference in SART EC between conditions was not significant, there was a significant condition by period interaction. As expected, participants tended to commit more EC over time in the single-task, as response time decreased. However, they tended to commit fewer EC over time in the dual-task (despite a similar speeding up). Despite the usual correlation between decreased response time and increased EC, Robinson and colleagues (2013) found that applying electric shocks to participants reduced EC without affecting response times. Wilson, de Joux, Finkbeiner, Russell, & Helton (2016) also found anxiety-provoking SART stimuli resulted in fewer EC without affecting response time, compared to neutral stimuli. The break in typical EC-response time coupling in the present dual-task condition is consistent with these outcomes.

One interesting finding was that subjective workload was quite similar when performing the SART task and dual-task. Though the mean memory task workload rating was 38/100, there was no increase in subjective workload to the SART task when both tasks were performed simultaneously. This supports the idea that the memory task utilizes different, readily available cognitive resources that do not compete with the resources being used by the SART task. However, when the mental demand and frustration subscales were analyzed, it was found that the dual-task was more mentally demanding than the SART task, but the SART task was more frustrating. Having the additional goal of remembering the scenario while performing SART may mitigate frustration (thus balancing out the global workload measure) without significantly impairing performance – at least in the specific conditions of this experiment. Compared to other subjective factors, frustration has not been extensively explored in SART or traditional vigilance research, and warrants further investigation.

Consistent with the MRT, results of the present research demonstrated that tasks not competing for the same cognitive resources may be performed in tandem at a similar performance level to if they were performed individually. Additionally, an increase in commission errors over time (seen in the single task condition) may be mitigated through inclusion of a secondary task, so long as that task does not compete for the same resources, and so long as the two tasks together do no overly tax the executive processor. This could have important implications for performance in real world tasks that induce a feed-forward ballistic motor program, such as shoot/no-shoot situations, but requires further exploration to better understand the specific factors that may help uncouple errors of commission from response time.

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