INDIVIDUAL DIFFERENCES IN SELF-CONTROL AND COGNITIVE RESOURCE DEPLETION DURING SUSTAINED ATTENTION

by

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DEDICATION

This is dedicated to my mom, Kim, who taught me the strength and persistence needed to complete this work. Her example showed me that when you put your mind to achieving a goal, you will succeed.

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I would like to thank the many friends, relatives, and supporters who have made this happen. My grandmother, Dr. Velma Eichhorn Harwood, who's career as a Captain in the United States Army during World War II inspired me from an early age. Drs. Shaw, McKnight, and Helton of my committee were of invaluable help through the entire process. Dr. Pamela Greenwood, my undergraduate honor's advisor, instilled in me a love for research and taught me the scientific rigor needed to conduct research well. Finally, thanks go out to all the friends who understood my many nights spent working instead of socializing.

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ABSTRACT

INDIVIDUAL DIFFERENCES IN SELF-CONTROL AND COGNITIVE RESOURCE DEPLETION DURING SUSTAINED ATTENTION

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George Mason University, 2019

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Sustained attention has many real-world applications such as air traffic control and driving. Researchers have typically studied sustained attention using basic laboratory tasks. The theoretical mechanisms of these tasks have been under question for years, with a particular focus on individual differences that predict a person's performance on these tasks. One potential individual difference is self-control, which has been theorized to be related to sustained attention but, to date, has not been sufficiently tested. In 3 studies, I investigated the effect of trait self-control and self-control depletion on two types of sustained attention tasks. Study 1 examined whether trait and state self-control relate to performance on a traditionally formatted vigilance task, and results indicated that there was no relation. Study 2 examined whether trait and state self-control related to performance on sustained attention to response task (SART) and results revealed a relation between trait self-control and performance on the SART. In study 3, I sought to

determine if the traditional vigilance task and the SART rely on a common mental resource. The results of study 3 suggest that the two tasks depend on separate cognitive resources. Taken together, the results of these studies showed that the effects of self-control on sustained attention task performance are inconsistent.

CHAPTER ONE: GENERAL DISCUSSION

President Harry S. Truman once wrote, "In reading the lives of great men, I found that the first victory they won was over themselves... self-discipline with all of them came first" (Larson, 1985; p. 128). Indeed, research shows that people with higher self-control tend to have greater personal and professional success (Mischel, Shoda, & Rodriguez, 1989), are better at resisting temptation (Mischel, Shoda, & Rodriguez, 1989), and commit fewer crimes (Muraven, & Baumeister, 2000). While self-control is often discussed as a personality trait, Baumeister and colleagues (Muraven, & Baumeister, 2000; Muraven, Tice, and Baumeister, 1998) posited that self-control is a limited cognitive resource that fluctuates throughout the day as people use it to complete a wide variety of tasks. In this line of research, we focus on the purported relationship between self-control - as both a personality trait and a state-dependent variable - and performance on sustained attention tasks (Muraven, & Baumeister, 2000; Muraven, Tice, and Baumeister, 1998).

The Integrative Self-Control model (Kotabe & Hoffman, 2015) states that the likelihood of successful self-control - choosing behaviors that align with the higher-order goals instead of immediate desires - is moderated by several factors, including Control Capacity, which is characterized as "all the potential non-motivational cognitive resources that a person possesses to control desire" (p. 620, Kotabe & Hoffman, 2015).

People use self-control as both an inhibitory (e.g., delay gratification, dieting, etc.) and excitatory (e.g., exercising, saving money, etc.) to complete behaviors beneficial to long-term goals in lieu of behaviors immediately pleasurable (De ridder, de Boer, Lugtig, Bakker, & van Hooft, 2011). According to Baumeister (Muraven, & Baumeister, 2000), self-control is directly responsible for attentional focus and sustained attention. That responsibility, however, bears little empirical support to date.

Perhaps the most appealing aspect of the self-control theory of sustained attention is the ability to train operators on self-control and enhance their sustained attention performance. Self-control is like a muscle according to the Strength Model of Self-control (Baumeister, Vohs, & Tice, 2007). If you 'exercise' self-control regularly to work towards goals, your 'self-control muscle' gets stronger. However, it's not clear if sustained attention depends on self-control, and self-control training on one task would transfer to other self-control tasks. Strength training is specific to the muscles exercised: if you only ever do bicep curls, you shouldn't expect your legs to get stronger. Cardiovascular training, however, generalizes to a degree. If you run regularly, the majority of your improvement will be in running, but you will see, to a lesser degree, increased stamina in other cardiovascular activities such as cycling, rowing, or swimming. The self-control theory of sustained attention suggests that improvements in self-control are general, like cardiovascular training. However, many other theories of sustained attention exist.

Sustained attention is often used as the broader term for two overarching tasks: vigilance tasks and motor control or motor inhibition tasks. Vigilance tasks are perceptually demanding and require external attention (i.e. to the stimuli), stemming from seminal work by Mackworth (1948). The most commonly accepted theory of declines in detections in vigilance tasks is cognitive resource theory. According to resource theory, vigilance performance declines with continuous performance due to the depletion of an unknown cognitive resource (Warm, Parasuraman, & Matthews, 2008). In contrast, motor inhibition tasks, such as the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), use easy to identify stimuli (e.g. numbers) and require attention to interrupt a prepotent motor response. Unlike vigilance tasks, performance on motor inhibition tasks often have a speed-accuracy trade-off (SATO) where participants tend to perform better when they respond more slowly, and vice versa (Dang, Figueroa, & Helton, 2018). The distinction between tasks may appear minor at first, however, overlooking the difference between the tasks causes problems in synthesizing past research. Results differ substantially and the mechanisms of action (i.e., the cognitive resources required) are likely to share little in common.

Throughout this line of research, we investigated the effect of trait and state-based self-control on the two most common vigilance tasks. The research presented in chapter two (Satterfield, Harwood, Helton, & Shaw, 2019) investigated the effect of a self-control depletion typing task on participants' performance during the abbreviated masked vigilance task. Additional information on the effect of trait self-control and self-control depletion on perceived distress were discussed. The research presented in chapter three (Harwood, Satterfield, Helton, McKnight, & Shaw, under review) investigated the effect of a self-control depletion typing task on participants' performance during the sustained attention to response task. The research in chapter four (Harwood, Helton, McKnight, Johnson, & Shaw, in prep) investigated the relationship of the abbreviated masked vigilance task and the sustained attention to response task; performance, cognitive resource depletion, and individual differences in trait self-control were discussed. Finally, chapter five discussing the impact of the overall line of research with regard to the aforementioned theories of sustained attention and practical implications.

CHAPTER TWO: DOES DEPLETING SELF-CONTROL RESULT IN POORER VIGILANCE PERFORMANCE?

Abstract

To investigate whether depleting self-control prior to vigilance results in a steeper vigilance decrement. The resource-control theory of vigilance asserts that an inherent bias toward self-generated mind-wandering draws attentional resources away from the primary task. This study seeks to test whether depleting self-control, the potential mechanism of self-generated mind-wandering, results in poorer vigilance performance. This study featured a between-subjects design where participants either completed a typing task which depleted self-control resources or a standard typing task that did not require self-control before performing a vigilance task. In the self-control depletion condition, participants typed a passage while omitting any "e" or "space" keys. In the standard typing task, participants typed the same passage without skipping any keys. Following both typing tasks, participants in both conditions completed an identical 12-minute vigilance task. Results demonstrated decreased accuracy and increased reaction times over time for both groups. Depleting self-control did not result in significant differences in accuracy, reaction time, nor a steeper vigilance decrement. These results provide evidence against resource-control theory and suggest that cognitive resource theory remains the predominant explanation for vigilance impairments. The mechanism of the vigilance decrement cannot be explained as a failure of self-control. It

is still unclear exactly what constitutes a ‘resource’. A better understanding of the nature of these resources can help researchers and practitioners identify how they can be replenished, which could enhance human performance in situations requiring vigilance such as baggage screening.

Introduction

The systematic study of vigilance can be traced back to the end of World War II, where there were attempts to explain why British naval radar operators missed critical signals of enemy combatants as watch periods progressed (Mackworth, 1948). This phenomenon, known as the vigilance decrement, has been the critical unit of study in sustained attention research since the inception of the topic. In its over 70 year history, no scientist has done more to advance our understanding of vigilance and the vigilance decrement than Joel Warm. He not only identified factors that are most directly related to vigilance decrements, such as event rate and signal probability (Warm, 1984; Warm & Dember, 1998), but also did much to advance our theoretical understanding of vigilance.

The purpose of this paper is to examine a trait or characteristic that may also contribute to our theoretical understanding of vigilance: self-control (Baumeister, Bratslavsky, Muraven, & Tice, 1998). There have been many theoretical explanations of the vigilance decrement (see Matthews*,* 2000 for a review), but explanations predominantly take one of two forms: overload and underload theories. Overload theories posit that excessive mental workload is the mechanism driving the decrement. Specifically, the resource depletion theorists suggest that vigilance tasks are taxing and effortful (Warm, Dember, & Hancock, 1996; Warm, Parasuraman, & Matthews, 2008) and the vigilance decrement results from a depletion of information-processing resources over time. Increasing task demands, such as demands associated with working memory, signal saliency, signal cueing, just to name a few, results in a steeper decrement

(Caggiano & Parasuraman, 2004; Hitchcock et al., 2003; Helton & Russell, 2011; 2013; Maclean et al., 2009; Parasuraman, 1979).

In contrast, underload theorists posit that the vigilance decrement does not result from high task demands. Instead the monotonous and under-stimulating nature of vigilance tasks results in disengagement from the task (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson et al., 1997). A leading underload theory, mindlessness theory, predicts that people withdraw attention from the vigilance task due to its tedious nature, resulting in “mindless”, or automatic behavior (Robertson et al., 1997). This results in under-responding to targets. However, this theory does not explain where attention is directed after it is withdrawn from the task. An extension of the mindlessness theory, the mind-wandering hypothesis, suggests that attention is redirected internally to task-unrelated thoughts (TUT) (Smallwood & Schooler, 2006). However, the mind wandering hypothesis does not explain the mechanism which causes increased mind wandering with time on task. Furthermore, if mind-wandering occurs because task demands are too low, this does not account for findings that vigilance tasks are stressful and that decrements increase with increased attentional demands (Dillard et al., 2014; Warm et al., 2008).

A newer theory, the resource-control theory of vigilance (Thomson, Besner, & Smilek, 2015) seeks to bridge resource theory, mindlessness theory, and the mind wandering hypothesis. (McVay & Kane, 2010, 2012). This theory posits that self-generated thought is the default state of a person and that mind wandering utilizes attentional resources that would otherwise be available for primary task performance.

This theory suggests that the vigilance decrement results from a failure of executive control to distribute attentional resources among external and internal thoughts and goals (Thomson et al., 2015). Performance decreases over time because this controlled processing can only be maintained for a limited amount of time. Failures of control result in attentional resources being consumed by mind wandering, leaving fewer resources allocated to the primary task. In other words, the decrement occurs because resources are being consumed to stave off boredom, or alternatively, the learned bias towards motor inaction (given the rarity of action in a low target probability vigil).

More compelling evidence for the resource-control theory of mind-wandering will come from an examination of individual differences traits that are associated with the governance of a learned behavior, namely self-control. Exerting self-control is an individual's attempt to change the way they would otherwise think, feel, or behave (Baumeister, Heatherton, & Tice, 1994, Muraven & Baumeister, 2000). In Baumeister's self-control or self-regulatory strength model, it is suggested that exercising self-control consumes self-control strength which is dependent upon resources. If these resources are drained, there are fewer resources available for subsequent tasks that require self-control. Previous studies have shown that performing acts of self-control such as controlling one's emotions (Muraven, Tice, & Baumeister, 1998), or resisting tempting foods like cookies (Baumeister et al., 1998) leads to poorer performance on a subsequent test of self-control. When it comes to vigilance, there is some evidence that suggests that dietary restriction leads to poorer performance on vigilance tasks (e.g. Green & Rogers, 1995; Green, Rogers, Elliman, & Gatenby 1996).

The aforementioned resource-control theory of vigilance is similar to the idea of self-control, in that proponents of the resource control theory of vigilance posit that executive control is needed to override the default bias to allocate resources to mind wandering and instead allocate resources to the primary task. If vigilance requires self-control, then draining the self-control resource should predict poorer performance on a subsequent vigilance task. In the current study, we compared participants that performed a task that has been shown previously to deplete self-control resources (Muraven, Shmueli, & Burkley, 2006) to participants that did not, and then had both groups perform a subsequent vigilance task. If the resource-control theory of vigilance is correct, participants in a self-control depletion condition should have poorer vigilance performance and a steeper vigilance decrement. If there is an inherent bias toward self-generated mind-wandering, reductions in self-control should result in fewer attentional resources allocated to the primary task. This study was designed to test that hypothesis.

Methods

Participants and Design

This research complied with the American Psychological Association code of Ethics and was approved by the Institutional Review Board at George Mason University. Informed consent was obtained from each participant. Seventy six undergraduate students (43 females; Age: M = 21.1 years, SD = 4.4) participated in the experiment. The experiment was a between-subjects design with the type of task preceding the vigilance task as the between-subjects factor. Participants were randomly assigned to which preceding task they performed before the vigilance task. Thirty eight participants performed a self-control depletion task before the vigilance task. The other thirty eight participants performed a comparable task that did not require self-control before the vigilance task.

Apparatus

Total Self-Control Scale. Trait self-control refers to the personality trait ability to self-override responses and alter personal states or behaviors that are more dominant responses (Baumeister & Alquist, 2009). To study self-control, we used a 36-item measure that examines trait self-control in relation to habit breaking, resisting temptation, and self-discipline (Tangney, Baumeister, & Boone, 2004).

Self-Control Depletion Typing Task. The self-control task was a typing task that has been used in previous self-control studies (Rieger, 2004; Muraven et al., 2006). Participants were instructed to retype a passage as seen on a computer screen, but to skip over and not type any “e” and “space” keys. Participants were also told to type as quickly, but as accurately as possible. Participants’ vision was occluded so that they were not able to see what they typed, although the computer recorded all keystrokes. This task requires self-control to override the natural inclination to type every letter. It has been used frequently for ego-depletion and has resulted in large effect sizes (Hagger, Wood, Stiff, & Chatzisarantis, 2010; Muraven et al., 2006). The experimenter stopped the participant after seven minutes.

Standard Typing Task. Participants in the control condition performed a standard typing task that involved retyping the same passage as the self-control depletion task, with the exception that participants were told to retype the passage exactly as it appeared on the computer screen. Participants in this condition also could not see what they were typing and were told to type as quickly, but as accurately as possible. The experimenter then stopped the participant after seven minutes.

Vigilance Task. All participants completed a 12-minute abbreviated vigilance task (Temple et al., 2000). This task has been shown to result in a vigilance decrement within five minutes and has the stress profile and right cerebral hemisphere dominance characteristic of longer vigilance tasks (Helton et al., 2007; Helton & Warm, 2008). The task was presented on a computer monitor and required participants to respond to a low frequency, low-saliency critical signal while ignoring neutral signals. Participants responded to a critical signal indicated by the capital letter, “O”, and ignored forward and backward-facing capital letter “D” neutral events. In order to increase workload, stimuli were partially masked by a field of small circles in the background. Stimuli were displayed for 40 ms with an interstimulus interval of 1000ms during which the mask remained. The task was divided into six blocks of two minute duration. During each block there were a total of 120 signals and 20% of the signals were critical (24 critical signals in each block).

Procedure

Participants first filled out a demographic questionnaire, followed by the pre-task portion of the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999). Following the questionnaires, participants completed a two minute typing test in order to obtain a baseline measure of participants’ typing speed (‘Aesop’s Fables’ test from

TypingTest.com). This test was administered to ensure there were no baseline differences in typing ability between the two groups. After the typing test, participants performed a two-minute practice of the vigilance task. The practice task mirrored the conditions of the vigilance task used for testing. In order to be included in the study, participants had to detect 80% of the critical signals in the practice with no more than 10% false alarms. If a participant failed to meet these criteria in the first practice, a second two-minute practice was completed. If these criteria were not met with two practice sessions, the participant was not included in the study. Following the vigilance practice, participants completed either the self-control depletion typing task or the standard typing task. The reason the depletion phase occurred after the vigilance practice was to minimize the amount of time between depletion and vigilance task performance. Next, participants completed the 12-minute vigilance task. Following the vigilance task, participants completed the post-task portion of the DSSQ and the Tangney, Baumeister, & Boone Self-Control Scale (Tangney et al., 2004). The entire duration of the experiment was approximately 60 minutes.

Results

Typing Speed Test

An independent samples t-test was performed on the adjusted words per minute of the typing test as a control to make sure there were no differences in general typing ability between the two groups. Results of the t-test revealed no significant difference in adjusted words per minute, $t(74) = -0.52$, $p = .60$, Cohen's $d = -0.12$ between the two groups.

Typing Task

An independent samples t-test was conducted on the performance of the typing task. Results on the typing task failed to save for one participant in the standard typing task condition. Therefore, for these results there are 37 participants in the standard typing task condition and 38 participants in the self-control depletion condition. Results revealed a significant effect for errors, $t(73) = 2.70$, $p < .05$, Cohen's $d = .62$. Errors were characterized as any spelling or grammatical mistake. For participants in the self-control depletion condition, this did not include pressing any "e" or "space" keys. Participants in the standard typing condition made significantly more errors when typing the paragraph ($M = 29.8$, $SE = 3.0$) compared to those in the self-control depletion condition ($M = 19.2$, $SE = 2.5$). Results also revealed a significant effect for the number of backspaces, $t(73) = 6.33$, $p<.05$, Cohen's $d = 1.46$. Participants in the standard typing condition hit the "backspace" key more ($M = 32.\ 4$, $SE = 3.1$) compared to participants in the self-control depletion condition ($M = 9.2$, $SE = 2.0$). These results likely point to a general slowing in typing speed in the self-control typing condition.

Vigilance Task

A 2 (Group) x 6 (Period) between-subjects Analysis of Variance (ANOVA) was performed on correct detections. Importantly, period of watch was discretized into six, 2-minute only for analysis purposes--participants experienced an uninterrupted 12-minute vigilance task. For this and all subsequent analysis, the Greenhouse-Geisser correction was used to correct degrees of freedom in cases where the sphericity assumption was not met. Results revealed a significant main effect for Period, $F(3.03, 224.52) = 34.50$, p<

.05, η2 = .32, indicating that correct detections decreased from periods 1 (*M* = 97.5%, *SE* = 0.4%) and 2 (*M* = 95.9%, *SE* = 0.8%) to period 3 (*M* = 93.3%, S*E* = 1.1%), and from period 3 to period 4 (*M* = 88.5%, *SE* = 1.7%), and from period 4 to period 6 (*M* = 83.1%, *SE* = 2.1%). Results did not reveal a significant main effect for Group, F(1, 74) = 0.13, p = .72, η2 = .002, nor a significant Group x Period interaction, F(3.03, 224.52) = 0.59, p = .63, η2 = .005. Because an extremely large effect size was considered a priori improbable and to be therefore conservative in our test of the null-hypothesis, we employed the unit-information Bayes factor (see Rouder, Speckman, Sun, Morey, & Iverson, 2009). For the overall mean correct detection (hit) difference between the experimental and control group, the Scaled-Information Bayes factor was 3.05 in favor of the null hypothesis. Generally a Bayes Factor greater than 3 is considered positive evidence in support of the given hypothesis (Kass & Raftery, 1995).We also calculated the mean slope of the correct detections regressed over periods of watch for the experimental and control group to perform a Bayes factor test for a difference in the actual decrement (see Helton & Warm, 2008 and Helton & Russell, 2012). In this case, the Scaled-Information Bayes Factor was 3.14 in favor of the null hypothesis. The false alarm rate was below 2% across both conditions and six periods, so false alarms were not analyzed further.

A 2 (Group) x 6 (Period) between-subjects ANOVA was also performed on reaction time. Results revealed a significant main effect for Period, F(4.11, 304.09) = 72.94, p< .05, η2 = .49. Reaction time increased from period 1 (*M* = 372.5, *SE* = 5.1), to period 2 (*M* = 404.0, *SE* = 6.1), to period 3 (*M* = 423.3, *SE* = 6.6), and increased from period 3 to period 5 (*M* = 443.1, *SE* = 7.4). Results did not reveal a significant main effect for Typing Task, $F(1, 74) = 0.003$, $p = .96$, $\eta2 = .000$, nor a significant Typing Task x Period interaction, $F(4.11, 304.09) = 0.75$, $p = .56$, $\eta2 = .005$. Table 1 presents the values for accuracy, false alarms, and reaction times for both groups across all periods.

Table 1 Vigilance Task Performance Metrics by Block

Condition	Performance Metric	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Control	Correct Detections	97.1 (0.7)	95.4 (1.3)	92.2 (1.6)	89.1 (2.6)	85.6 (2.6)	81.8 (3.1)
	False Alarms	1.5 (0.2)	1.0 (0.2)	1.1 (0.4)	1.5 (0.3)	1.6 (0.3)	2.0 (0.4)
	Reaction Time	369.6 (6.9)	405.3 (8.3)	424.7 (9.4)	430.0 (8.8)	447.6 (10.6)	446.6 (8.7)
Depletion	Correct Detections	97.9 (0.5)	96.5 (1.0)	94.4 (1.3)	87.8 (2.3)	85.1 (2.3)	84.4 (2.8)
	False Alarms	1.7 (0.4)	0.9 (0.2)	0.8 (0.2)	1.5 (0.3)	1.8 (0.3)	2.3 (0.4)
	Reaction Time	375.4 (7.6)	402.7 (8.8)	421.9 (9.3)	435.9 (10.4)	438.6 (10.4)	445.4 (10.6)

DSSQ

Pre- and post- scores from the DSSQ were standardized against normative data from a large British sample (Matthews et al. 2002; Matthews et al. 1999).

Equation 1 DSSQ Standardization Formula

z = (raw score – mean of normative sample) / standard deviation of normative sample

Factor scores for Task Engagement, Distress, and Worry were calculated using regression weights from the normative sample. Factor scores are distributed with a mean of 0 and a SD of 1, so that values calculated for a sample represent a deviation from normative values in standard deviation units. The analysis revealed that the only dimension that revealed a difference between the two conditions was the Distress dimension, $t(74) = -2.43$, $p = .02$, Cohen's $d = -0.56$. Participants who performed the self-control depletion typing task prior to performing the vigilance task reported a significant increase in distress ($M = 0.68$, $SE = 0.11$) compared to participants in the standard typing task condition ($M = .26$, $SE = 0.\ 13$). Similar to the Bayesian analysis conducted on the correct detection results, we also conducted a Bayes Factor test for the distress scale. In this case, the Scaled-Information Bayes Factor was 4.13 in favor of the alternative hypothesis.

An examination of the three subscales of the Distress dimension of the DSSQ (hedonic tone, tense arousal, and confidence and control) revealed that hedonic tone (i.e. positive mood) was the only Distress subscale that significantly differed between the two groups. These results can be viewed graphically in Figure 1. Participants who performed the self-control depletion task prior to engaging in the vigilance task reported increased feelings of unpleasantness after the vigil (Change score = -.61, $SE = -.12$) than those participants in the standard typing task condition (Change score = .21, $SE = .12$).

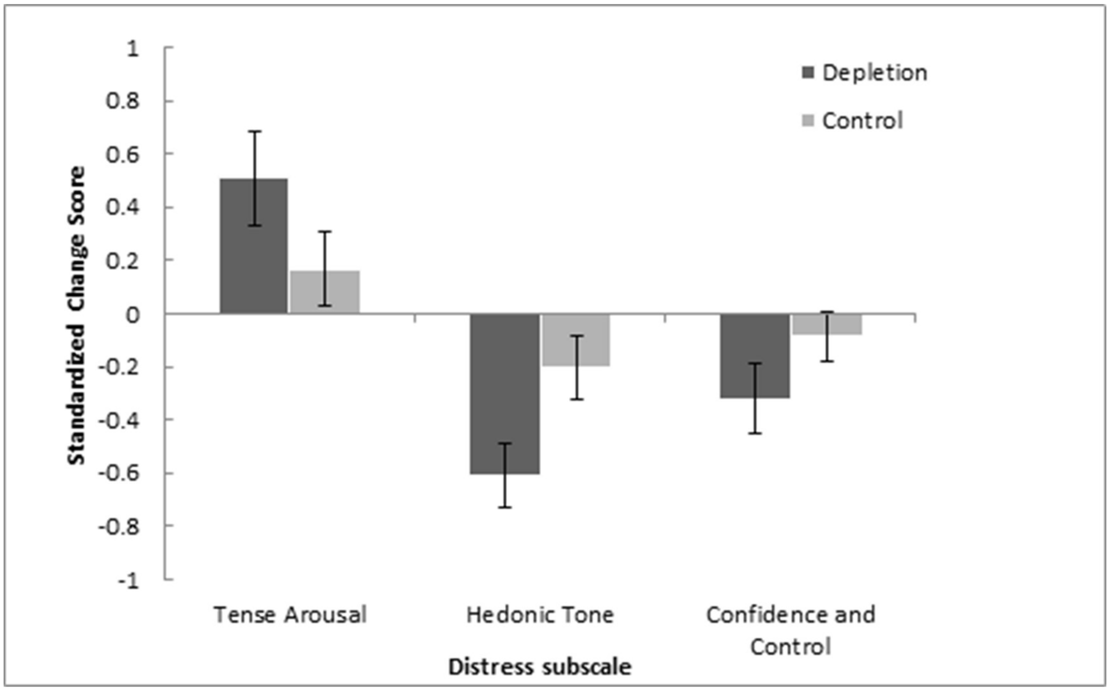

Figure 1 Standardized Distress subscale scores plotted for Tense Arousal, Hedonic Tone, and Confidence and Control for the Self-control Depletion and Control groups. Error bars are standard error

Trait Self-Control

An independent samples t-test was performed on scores from the Tangney Self-Control Questionnaire to evaluate any differences in the two groups. Results revealed no significant difference in self-control between the two conditions, t(74) = 1.36, p = 0.18, Cohen's d = 0.31. More importantly, self-control did not significantly correlate with any of the dependent measures of correct detection, reaction time, or typing performance (p> .05).

Discussion

The purpose of the current experiment was to explicitly test the resource-control theory of vigilance by examining a trait that should be associated with that theory, self-control. Although significant performance decrements were found in both accuracy and reaction time, differences in performance between the self-control depletion group and the control group were not observed. Analyzing the results from a Bayesian perspective found strong evidence for no main effect between the two conditions for accuracy nor reaction time. Researchers have recently surmised that a relation between self-control and sustained attention performance could exist (e.g. Langner & Eickhoff, 2013, Shaw et al., 2013, Steinborn & Huestegge, 2016), and the resource-control theory makes this prediction explicitly (Thomson, Besner, & Smilek, 2015), but to our knowledge, this is the first attempt to explicitly look at the potential causal relation of self-control resource depletion and vigilance.

Intriguingly, trait self-control, as measured by the Tangney self-control scale, was not associated with the self-control depletion task. The self-control typing task has been previously used as a means of depleting the self-control resource pool (Muraven et al. 2006, Rieger, 2004), and has been shown to affect future tasks that require self-control. It deserves mention that prior research has shown that different measures of self-control only correlate moderately with each other (Duckworth & Kern, 2011). In fact, there is stronger evidence for convergent validity among questionnaire measures than with task measures, possibility suggesting that with self-control tasks there could be a great deal of task-specific error variance. This is a testament to a growing concern that self-control is difficult to define and quantify, and that the specific mechanisms underlying self-control depletion and regulation need to be better refined (e.g. Inzlicht & Schmeichel, 2012). It should be noted, though, that it is often the case that the underlying reliability of tasks is often underreported, which could serve to conflate convergent validity estimates.

While the self-control typing task did not impact vigilance performance, the task did elevate self-reports of subjective distress. Participants in the experimental condition who performed the typing task reported increased unhappiness and aversive psychological state after the vigil than those in the control condition. Finkbeiner, Russell, and Helton (2016) also noted a dissociation between feelings of distress and performance in their study examining different types of break activities during a vigil. A number of the non-resource depletion theories of vigilance entail that the subjective unpleasantness of vigilance tasks results in the participant's withdrawal of their attention from the task and this withdrawal is the cause of the decrement (Kurzban et al., 2013; Thomas et al., 2015). If this is the case, it is odd that participants who were in the experimental condition did report increased distress (subjective unpleasantness) but with no apparent impact on the decrement. If the decrement is caused by the participant's attempt to mentally escape an unpleasant experience, the increased mental displeasure caused by making the participant perform a difficult and tedious task prior to the vigil should result in more desire to escape and thus, worse performance. This did not happen. Perhaps, after some moderate level of unpleasantness is experienced there is no sensitivity to further unpleasantness, but this strains believability. A more parsimonious explanation is that the vigilance decrement is due to the depletion of the specific cognitive resources necessary to perform the task (Helton & Russell, 2015; 2016). The decrement is not due to some generalized loss of self-control nor is the decrement due to the withdrawal of attention due to subjective aversive state, such as boredom (Kurzban et al., 2013; Langner et al, 2011; Thomas et al., 2015).

There is some previous research that has suggested a relation between self-control and vigilance, but to date, that evidence is loose at best. For example, studies by Green and associates have suggested that dietary restriction is related to vigilance performance, although that research did not identify self-control as the specific mechanism of action (Green & Rogers, 1995; Green et al., 1996). Moreover, those studies used particularly short versions of a cognitive vigilance task, unlike the sensory vigilance task used here, and could involve more nuanced mechanisms (e.g. specific elements of diet that support cognitive function). In another study, it was shown that a physiological measure that has been shown to be sensitive to cognitive resource expenditure (e.g. Harwood, Greenwood, & Shaw, 2016) reveals differences between individuals high in trait self-control than with low trait self-control (Becker, Mandell, Tangney, Chrosniak, & Shaw, 2015). That study showed that while high self-control participants had better resource allocation strategies, it was not associated with superior performance in that group. Given prior studies and the findings of the current study, it is difficult to assert that a clear relation between self-control and vigilance exists. Future research may want to consider the inclusion of different types of self-control tasks that have been used in the literature. For example, delayed gratification tasks require participants to make a distinction between smaller, immediate rewards, and larger, delayed rewards. It could be the case that self-control is a multi-dimensional construct and that different types of self-control tasks could be reflective of different aspects of self-control (Duckworth & Kern, 2011).

The research presented here is important because of the theoretical question that lies at the crux of the paper and has plagued cognitive resource theorists for several years: what is a resource? A potential mechanism may have been offered by the advocates of the resource-control theory of vigilance, but those arguments, unfortunately, don't withstand empirical scrutiny. Even in the self-control literature, theorists identified glucose as a candidate physiological resource, reporting findings that a greater amount of glucose was consumed during self-control tasks, which suggests that glucose could be the causal mechanism for self-control depletion (cf. Gailliot & Baumeister, 2007; Gailliot et al., 2007). However, a more recent evaluation of the effects of glucose has revealed that the effect is not as strong as previously thought (Kurzban, 2010). Nevertheless, it should be noted that cognitive resource theory is not without its faults, and has been also criticized for its circularity (c.f. Navon, 1984). Also, it is currently unknown whether or not performance impairments in sustained attention are a function of resource drainage or changes in resource allocation policy. The vigilance decrement is often interpreted in terms of depletion, and this is supported by neurophysiological evidence (e.g. Hitchcock et al., 2003). However, more recent research that has focused on individual differences in vigilance has revealed that some of the neurophysiological findings could potentially be interpreted in terms of an observer's allocation policy (Becker, Mandell, Tangney, Chrosniak, & Shaw, 2015; Mandell, Becker, VanAndel, Nelson, & Shaw, 2015; Shaw, Nguyen, Satterfield, Ramirez, & McKnight, 2016; Shaw, Satterfield, Ramirez, & Finomore, 2013). It seems that the search for the elusive "resource" in vigilance research continues.

The self-control depletion task did not impact subsequent vigilance performance, a result that does not seem to support the resource control theory account of vigilance. It should be noted, though, that there are several unanswered questions that should be explored before that conclusion becomes definitive. For example, although the procedure for the self-control depletion task was carried out in the current study was modeled closely after Muraven et al. (2006) it is currently unknown how long it takes to deplete the self-control resource pool, and for how long it will remain depleted. Indeed, there is evidence that rest improves performance on standard vigilance (Helton & Russell, 2015) and cognitive vigilance tasks (Steinborn & Huestegge, 2016), and there is even some evidence that the introduction of an additional task into a vigil may have a restorative effect on vigilance performance (Ralph, Onderwater, Thomson, & Smilek, 2017). Rest breaks are presumed to have a restorative effect via the replenishment of information processing resources (Helton & Russel, 2015), and it is proposed that the introduction of another task has a restorative effect via increasing energetic arousal (Ralph, Onderwater, Thomson, & Smilek, 2017; Steinborn, Langner, & Huestegge, 2016) or goal reactivation when switched back to the original task (Ariga & Lleras, 2011; although see Helton & Russell, 2011). Clearly identify the underlying processes involved has proven difficult, and the answer to the question as to whether the resource pool being replenished is attributable to a generalized self-control resource pool or a more domain- specific pool of attentional resources is still unknown. It is the belief of the authors, given the current set of data, that vigilance performance relies on more domain-specific resources. Despite the suggestion that self-control and vigilance are directly related (cf. Muraven &

Baumeister, 2000), it appears that the generalized pool of self-control resources do not directly modulate vigilance. More research should be conducted on the self-control resource depletion and its specific relation to cognitive performance.

There are also practical considerations that are raised with the current research. In operational settings where vigilance is needed, such as baggage inspection and combat identification (Shingledecker et al., 2010), strategies to enhance overall vigilance or to identify operators less susceptible to decrement are often sought. This begs the question as to what types of interventions and operators can be employed for jobs that require vigilance. If self-control was a possible explanatory mechanism, then it could have been possible to select operators based on trait self-control, or perhaps even the extent to which operators are susceptible to self-control depletion. Given the results of the current study, it seems as though self-control may not be sufficient as a selection criterion for vigilance. Researchers and practitioners may instead want to focus on intervention and selection approaches that are consistent with the cognitive resource theory of vigilance. With regard to intervention approaches that have shown to be successful in vigilance, research points to rest breaks (e.g. Helton & Russell, 2015; Steinborn & Huestegge, 2016) and stimulants (e.g. Temple et al., 2000) as means to replenish cognitive resources available for vigilance performance. With regard to selection, there has been some promise in using multivariate assessment techniques that combine performance, self-report, and neurophysiological indices to predict future vigilance performance (Matthews et al., 2014).

CHAPTER THREE: THE ROLE OF STATE AND TRAIT SELF-CONTROL ON INHIBITION AND MOTOR CONTROL

Abstract

Researchers suggested that self-control is a limited cognitive resource used to complete a myriad of processes, including sustained attention. Past research showed that trait self-control affects some sustained attention tasks. However, little research has investigated the effect of self-control as a resource (i.e. state-dependent). This experiment investigated the effect of self-control (trait and state) on a sustained motor-inhibition task (e.g. sustained attention to response task; SART). State self-control was manipulated using a between-subjects design - participants in the experimental condition completed a task designed to deplete self-control prior to performing the SART while the control condition completed a modified version that did not deplete self-control. Trait self-control predicted performance on the SART, but the depletion task had no detectable effect. Trait self-control ought to be considered in future work with motor-inhibition tasks, such as the SART, and for personnel selection in real-world tasks that the SART models.

Introduction

Researchers suggest that people use self-control (a resource) to focus their attention while performing a task (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Tice, & Baumeister, 1998; Muraven, & Baumeister, 2000). Many tasks - including critical public safety jobs (e.g. Air Traffic Control) - require sustained attention across a full workday. Sustained attention tasks (i.e., those tasks that require a skillful application of focus) may depend on general self-control. However, in a prior study employing a low target probability vigilance task, we failed to demonstrate a relationship between generalized self-control and target detections. (study 1, this volume; Satterfield et al., 2019). The purpose of the current study was to determine if self-control affects a different kind of target detection task in which the response mode is altered. Specifically, we look at self-control's relationship to performance on a high target probability task, the sustained attention to response task (SART; Robertson et al., 1997).

Baumeister conceptualized self-control as a limited resource that is depletable with continuous use (Muraven, & Baumeister, 2000). Self-control has been implicated as a critical aspect of human performance (Tangney, Baumeister, & Boone, 2004; Mischel, Shoda, & Rodriguez, 1989). Those who possess more self-control tend to perform better on a variety of cognitive tasks (Muraven, & Baumeister, 2000), tend to manage their affairs better (Muraven, & Baumeister, 2000), and succeed more than those who possess little self-control (Mischel, Shoda, & Rodriguez, 1989). Low self-control in children leads to poor delayed gratification and impulsive behavior (Mischel, Shoda, & Rodriguez, 1989). Teens with low self-control are more susceptible to peer-pressure (e.g.

drug use), get in more trouble at school, and break the law more often. Adults with higher self-control tend to be top performers at work and high achievers in their personal life (Muraven, & Baumeister, 2000). Thus, self-control appears to be a key determinant of success throughout life.

Many definitions of self-control reference resources. For example, the Integrative Self-Control model (Kotabe & Hoffman, 2015) states that the likelihood of successful self-control - choosing behaviors that align with the higher-order goals instead of immediate desires - is moderated by several factors, including Control Capacity, which is characterized as "all the potential non-motivational cognitive resources that a person possesses to control desire" (p. 620, Kotabe & Hoffman, 2015). Muraven, Tice, and Baumeister (1998) state that self-control "is limited in such a way that expending it is followed by a period of scarcity, until it builds up again." (p. 775). Thus, self-control may be viewed as analogous to a gas tank in an automobile. The gas tank may be emptied through use (resource depletion), filled up at the station (resource restoration), or used conservatively in fuel-efficient cars or driving habits (resource efficiency). Furthermore, the gas tank may be enlarged to increase capacity (resource capacity). Thus, self-control may exist as a resource that may be depleted and restored. When depleted, self-control may be wasted or used wisely. Through other means, the ability to store the resource may change over time.

Attention and, perhaps more importantly, sustained attention appear relevant to self-control. Attentional control may be just one form where self-control manifests. Sustained attention is often used as the broader term overarching two types of tasks: (1)

vigilance tasks and (2) motor control or motor inhibition tasks. Vigilance tasks are perceptually demanding and require external attention (i.e. to the stimuli), stemming from seminal work by Mackworth (1948). The most commonly accepted theory of declines in detections in vigilance tasks is cognitive resource theory. According to resource theory, vigilance performance declines with continuous performance due to the depletion of an unknown cognitive resource (Warm, Parasuraman, & Matthews, 2008). In contrast, motor inhibition tasks, such as the Sustained Attention to Response Task (SART; Robertson et al., 1997), use easy to identify stimuli (e.g. numbers) and require attention to interrupt a prepotent motor response. Unlike vigilance tasks, performance on motor inhibition tasks often have a speed-accuracy trade-off (SATO) where participants tend to perform better when they respond more slowly, and vice versa (Dang, Figueroa, & Helton, 2018). The distinction between tasks may appear minor at first, however, overlooking the difference between the tasks causes problems in synthesizing past research. Results differ substantially and the mechanisms of action (i.e., the cognitive resources required) are likely to share little in common.

Baumeister theorized that tasks requiring “vigilance” ([sic]; really, sustained attention) depend on self-control (Muraven, Tice, & Baumeister, 1998; Muraven, & Baumeister, 2000); people with greater self-control perform better on these sustained attention tasks. Furthermore, the theory posits that self-control - in the case of these performance tasks - is a resource that may be depleted and restored as opposed to a trait that remains stable over time and generally does not diminish (Muraven, & Baumeister, 2000). Self-control as a cognitive resource would complete a missing link in the most widely accepted theory of sustained attention - resource theory. In resource theory, a person's ability to perform a sustained attention task depends on the availability of an unidentified and limited cognitive resource that depletes with use but replenishes with rest (Warm, Parasuraman, & Matthews, 2008). Baumeister's self-control theory simply suggests that self-control is the unidentified resource discussed in the resource theory of sustained attention. Consider how the theory might unfold in sustained attention task performance. If a person depletes her self-control resources, then she ought to perform below her abilities until she is able to replenish those resources (e.g. through rest). A few older studies suggested that depleting self-control prior to a vigilance task resulted in poorer performance (e.g. higher error rates, longer reaction times). One such study (Green, & Rogers, 1995) found that dietary restriction - often used to alter self-control - lead to poorer vigilance performance. Unfortunately, little to no work investigated the process or mechanism of action, as dietary restriction can reflect general fatigue or anhedonia rather than limited self-control. A closer examination of the underlying mechanism of action would help us understand if and how self-control affects sustained attention.

Cognitive mechanisms underlying vigilance can be investigated by measuring temporal brain activity (e.g., fNIRS or TCD). For example, a common finding in vigilance is that as performance declines, there is a concomitant decline in cerebral blood flow velocity, as indexed by Transcranial Doppler Sonography (Harwood, Greenwood, & Shaw, 2017; Mandell et al., 2015; Shaw et al., 2009; Shaw et al; 2016; Shaw et al; 2019). This has been interpreted as evidence that CBFV provides an indication of cognitive resource consumption. If self-control is the resource that makes the skill of vigilance easier, CBFV- the speed with which blood flows to the brain - would be higher overall in people with higher trait self-control and deplete slower over time. Becker and colleagues (2015) investigated the relationship of trait self-control on cognitive resource consumption (via CBFV) during a vigilance task. They reported that people with higher trait self-control had lower CBFV but performed at the same level as people with lower trait self-control during the abbreviated masked vigilance task (Temple et al., 2000). Thus, people with higher self-control were more efficient during the vigilance task. This study (Becker et al., 2015) simply showed an individual difference based on trait self-control, not a causal relationship of self-control depletion and vigilance performance.

In study 1, we tested the causal relationship of self-control depletion on vigilance performance--that is, whether people performed worse on the vigilance task if they depleted their self-control just before the vigilance task. Participants in a self-control depletion group completed the 'Inhibiting a Natural Impulse' typing task designed to tax self-control (Muraven, Shmueli, & Burkley, 2006), while a control group typed normally for an equivalent amount of time. Using the same vigilance task as Becker et al. (2015), we found no significant differences in vigilance performance between groups (study 1, this volume; Satterfield et. al., 2019). Perhaps self-control is not a critical aspect of vigilance tasks (i.e Mackworth clock test, Mackworth 1948; Abbreviated masked Vigilance task, Temple et al., 2000) that are primarily measures of awareness of external stimuli. Perhaps self-control reflects more limitations in the ability to interrupt a prepotent motor response (e.g. the SART). To our knowledge, the effect of self-control depletion on SART performance has not been investigated, which brings us to the present experiment.

In the present experiment, we replicated the study 1 protocol using the SART instead of a vigilance task, to investigate the relationship of self-control - as both a trait and a state - on a motor inhibition task. If trait self-control predicts SART performance, we could use self-control as a selection criterion for real-world tasks similar to the SART, such as fratricide (i.e. soldiers; Wilson, Head, De Joux, Finkbeiner, & Helton, 2015; Head, Tenan, Tweedell, LaFiandra, Morelli, Wilson, ... & Helton, 2017; Wilson, De Joux, Finkbeiner, Russell, Retzler, & Helton, 2018). If there is a relationship between self-control and inhibition, we could develop protocols to improve performance by providing personnel with sufficient rest periods, allowing them to replenish their self-control before returning to their task (Biggs, Cain, & Nitroff, 2015; Helton, & Russell, 2015; 2017). Below, we listed our three research questions (Q) and the associated hypothesis (H) to each:

Q1. Does the depletion of self-control prior to the SART result in decreased performance?

H1. We predicted that the experimental depletion group would have significantly worse performance (i.e. lower accuracy, longer reaction times, or both) compared to the control group.

Q2. Does trait self-control predict SART performance beyond the speed-accuracy tradeoff?

H2. We predicted a significantly positive relationship between trait self-control and accuracy.

Q3. Does the depletion of self-control prior to the SART result in increased perceived stress during the SART?

H3. We predicted significantly higher self-reported distress in the experimental depletion group compared to the control group.

Methods

Participants and Design

This experiment was approved by the Institutional Review Board prior to this experiment. Participants gave informed consent and received course credit for their participation. We recruited 60 participants (42 female) from a mid-Atlantic university. We choose to recruit 60 participants based on an a priori power of .95 (d= .25, alpha = .05). Eight of the participants were removed as outliers (see section 3.1), leaving 52 in the final sample. Participants ranged in age from 18 to 23 (M=20.42, SD=2.09), had normal or corrected-to-normal vision, and were right-handed. Participants were randomly assigned to either a control group (N=26) or self-control depletion group (N=26). For the final sample demographics, see table 2 below.

Table 2 Final Sample Demographics

Condition	N (sex)	Age	Education	Typing Ability	Trait Self-Control
Control	26 (18F)	20.2 (2.0)	13.3 (2.8)	89.2 (14.4)	99.9 (14.15)

Condition	N (sex)	Age	Education	Typing Ability	Trait Self-Control
Depletion	26 (18F)	20.6 (2.2)	14.1 (1.5)	94.0 (6.6)	100.15 (19.68)

Apparatus

Questionnaires. We used a demographic questionnaire that covered basic demographic information. We used the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999) before and after the experiment to assess changes in distress, engagement, and worry. We used the 36-item Total Self-control Scale (range 36-180; Tangney, Baumeister, & Boone, 2004) to measure trait self-control. These scales were identical to those used in Chapter 2.

Individual Typing Ability. To ensure that any changes related to the depletion manipulation were not attributable to typing skill, we used a two-minute online typing test (www.typingtest.com/) to assess individual typing skill. For this test, participants were told to type a story (Aesop's fables) presented on the top half of the screen as quickly and as accurately as possible. The program calculated the participants' words per minute, the number of errors, error percent, and adjusted words per minute. This task was identical to that used in Chapter 2.

Inhibiting a Natural Impulse Typing Tasks. Participants in the self-control depletion group copied a story from a text document into a blank window. The participants were told they would not be able to see the words as they typed, but they could use the 'backspace' key to correct mistakes. Participants in this group were told to omit the “E”s and spaces in the story. Participants were told to type as quickly and accurately as possible until the experimenter told them to stop. The researcher stopped the participants after 7 minutes. A program developed in Python logged all keystrokes including backspaces. The researchers coded each participant's output for words per minute (WPM), grammar/spelling errors, backspaces, Adjusted WPM, and the number of Es and spaces used. Finally, researchers calculated words per minute and adjusted words per minute. This task was modeled after previous research (Muraven, Shmueli, & Burkley, 2006) and was identical to that used in study 1 (Satterfield et. al., 2019).

Participants in the control group copied a story that was identical to that in the experimental group. They were given the same instruction as the experimental group but were permitted to use “e”s and spaces (Muraven, Shmueli, & Burkley, 2006). The participants were told they would not be able to see the words as they typed, but they could use the ‘backspace’ key to correct mistakes. Participants were told to type the story as quickly and accurately as possible. The researcher stopped the participants after 7 minutes. The same variables were logged and coded as in the ‘Inhibiting a Natural Impulse’ Typing Task except for the number of “E”s and spaces used. This task was modeled after previous research (Muraven, Shmueli, & Burkley, 2006) and was identical to that used in Chapter 2.

Sustained Attention to Response Task. We used a twelve-minute SART (Robertsonet al., 1997). The program randomly displayed the numbers one through nine. The participants were told to monitor the screen and press the spacebar for all numbers, but withhold their press when they see the number ”3”. Each signal was presented for 250 ms with an average inter-stimulus interval of 900 ms (min = 750 ms; max= 1050). The overall event rate was 52 events per minute with a target event rate of 11 percent (i.e. one in nine). In every two-minute block, each number was randomly presented 12 times. Each block included 12 targets. Blocks were discretized for analysis only - participants experienced the task as 12 consecutive minutes.

For each block, we reported three performance metrics: (1) correct withholds, (2) errors of omission (false alarms), and (3) 'go' reaction time. Correct withholds were when the participant correctly refrained from hitting the spacebar when the target stimuli (i.e. '3') appeared. Errors of omission were when the participant incorrectly withheld response to neutral stimuli (all numbers except 3). 'Go' reaction time (referred to simply as reaction time) was the time it took participants to respond to neutral stimuli, incorrect reaction times to target stimuli were not included in this metric.

Procedure

Participants were greeted and shown to a windowless experiment room. Participants read and signed a consent form, and completed the pre-experiment DSSQ. They then completed a 2-minute practice version of the SART. In order to continue, the participants' accuracy had to be higher than 90 percent. Participants then completed the online typing test and their assigned 'Inhibiting a Natural Impulse' typing task. They then completed the main trials of the SART. Finally, participants completed the post-experiment DSSQ, the biographic questionnaire, and the trait self-control scale. The procedure was identical to study 1 except that participants completed the SART instead of the abbreviated masked vigilance task (Temple et al., 2002).

Data Analysis

We used the R programming language (version 3.4.4; Ihaka, & Gentleman, 1996; Team, 2018) and several packages: ‘tidyverse’ (version 1.2.1; Wickham, 2017), ‘lme4’ (version 1.7.1; Bates Maechler, Bolker, & Walker, 2014), ‘lmerTest’ (version 3.0.1; Kuznetsova, Brockhoff, & Christensen, 2016), and ‘BayesFactor’ (version 0.9.8; Rouder, Speckman, Sun, Morey, & Iverson, 2009) due to the flexibility and power to handle unbalanced designs. Our use of the ‘lme4’ and ‘lmerTest’ packages allowed us to test regression models with mixed effects. Specifically, we were concerned that the two experimental groups may have significantly different intercepts in the first block of the SART due to the manipulation. Thus, linear mixed-effects models provided more accurate parameter estimates and hypothesis tests than fixed-effects models (e.g. ANOVA or ANCOVA).

Results

Data Management

We removed eight participants due to extreme data (greater than 3 standard deviations from the mean; Cohen, Cohen, West, & Aiken, 2013). Two participants were removed for extremely low individual typing ability, one for high typing errors committed, and five for high false alarm rates. Fifty-two participants remaining in the final sample, twenty-six per group.

Experimental Manipulation Check

We ran two manipulation checks to see if trait self-control related to the outcome measures of the 'Inhibiting a Natural Impulse' typing task (Muraven, Shmueli, & Burkley, 2006) with the prediction that those with higher self-control ought to be less susceptible to the depletion manipulation. We ran two regressions predicting (1) Adjusted Words per Minute (Adj. WPM) and (2) total errors using trait self-control, group (dummy coded: control = 0), and their interaction as predictors. Trait self-control ought to be positively related to Adj. WPM; conversely, trait self-control ought to be negatively related to total errors (Muraven, Shmueli, & Burkley, 2006). By including the interaction in the model, we checked if trait self-control was affecting one group more than the other. The model predicting Adj-WPM was significant and accounted for approximately 26 percent of the variance in the data (Adj-R^2 = .26, $F(3, 48)$= 7.064, $p < 0.001$, Cohen's f^2 = .33, power =0.947) Adj. WPM was marginally predicted by trait self-control (b= 0.19, t = 1.88, p = 0.066). The main effect of group was not significant (b= -6.21, t = -0.50, p = 0.62), nor was the trait self-control by group interaction (b= -0.003, t = -0.028, p = 0.978). The model predicting total errors was significant and accounted for approximately 12 percent of the variance in the data (Adj-R^2 =.12, $F(3,48)$ = 3.344, p = 0.027, Cohen's f^2 = .13, power = 0.565). There was a significant main effect of group (b = -85.71, t = -2.73, $p < 0.01$), trait self-control (b = -0.51, t = -2.02, $p < 0.05$), and a significant interaction (b = .74, t = 2.44, $p < 0.05$). These analyses are comparable to analyses used in study 1 (Satterfield et al., 2019).

We ran a t-test to check for a significant difference in trait self-control between groups since we did not block on trait self-control during random assignment. There was no significant difference of trait self-control between groups (t(52.971) = -0.13619, p = 0.8922, Cohen's d = 0.015, power = 0.05; see figure 1 below).

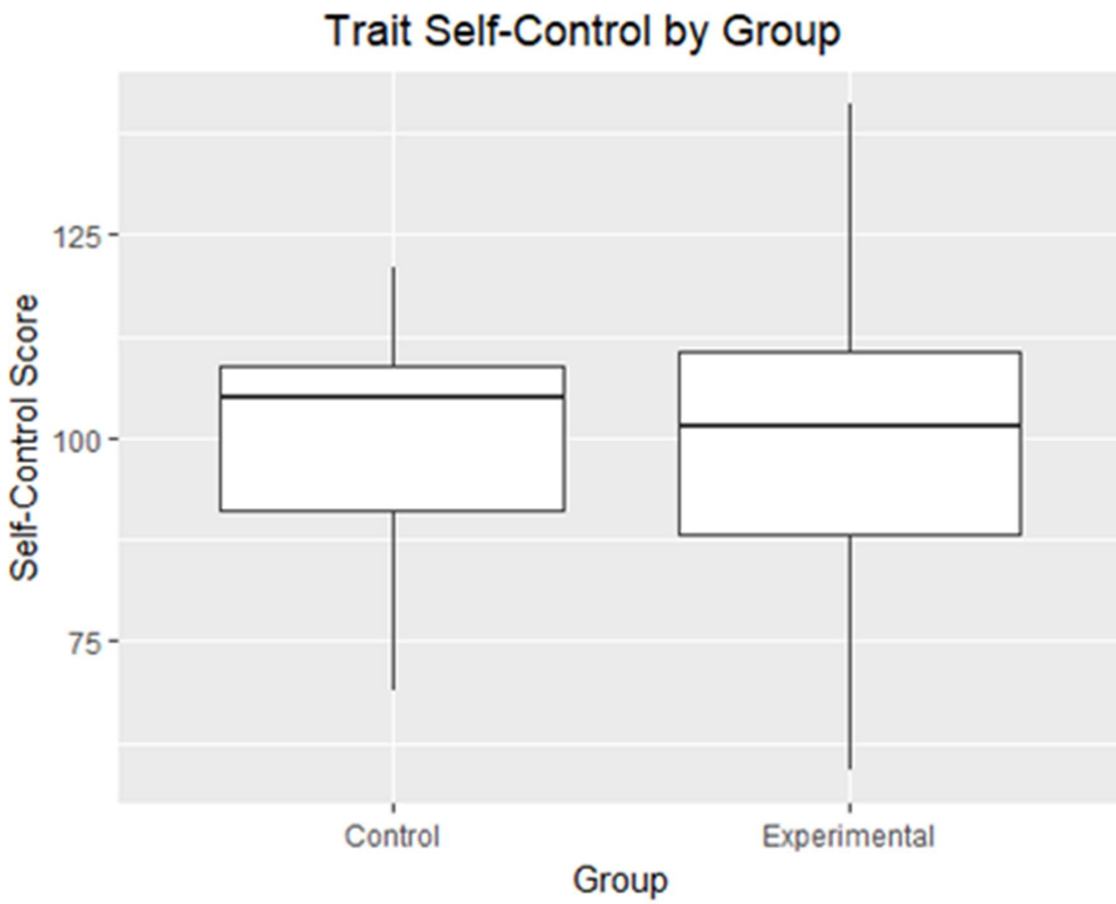

Figure 2 Trait self-control scores by group

Research Questions

Q1. Does the depletion of self-control prior to the SART result in decreased performance? We ran a regression model predicting correct withhold rate by group, block, the group by block interaction, 'go' reaction time, and trait self-control with a random intercept for each participant. The model was significant (Adj-R^2 = .41, $F(5, 306)$= 44.86, p<0.001, Cohen's f^2 = 0.69 , power = 0.997). There was a negative main effect of block (b = -.021, t = -2.802, p <0 01), positive main effect of reaction time (b = 0.0027, t = 13.43, p < 0.0001), and a positive main effect of trait self-control (b = 0.0022, t = 3.92, p = 0.0001). There was no main effect of group (p=0 .67) nor a block by group interaction (p = 0.97). We ran a regression model predicting omission error rate by group, block, the group by block interaction, reaction time, and trait self-control, but the model was not significant (Adj-R^2 = .01, $F(4, 307)$ = 1.834, p = 0.12, Cohen's f^2= 0.01 , power = 0.998). We ran a linear regression predicting reaction time using group, block, the group by block interaction, and trait self-control, but the model was not significant (Adj-R^2 = 0.006, $F(4, 307)$= 0.56, p= 0.69, Cohen's f^2= 0.006, power = 0.998). For performance metrics by condition, see table 3 below.

Table 3 Sustained Attention to Response Task Performance Metrics by Block.

Condition	Performance Metric	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Control	Correct Withholds	.57 (.18)	.56 (.21)	.48 (.22)	.47 (.20)	.46 (.22)	.48 (.22)
	Omission Error Rate	.007 (.008)	.007 (.007)	.008 (.006)	.010 (.010)	.009 (.008)	.008 (.007)
	Reaction Time	310 (36)	308 (44)	300 (43)	302 (44)	304 (51)	301 (54)

Condition	Performance Metric	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Depletion	Correct Withholds	.65 (.17)	.51 (.22)	.48 (.20)	.50 (.22)	.49 (.20)	.46 (.21)
	Omission Error Rate	.005 (.003	.007 (.005)	.009 (.007)	.011 (.012)	.011 (.010)	.009 (.010)
	Reaction Time	316 (42)	309 (50)	296 (45)	296 (47)	305 (54)	299 (51)

Since the treatment group did not significantly predict SART performance, we provide group-based t-tests and corresponding Bayes Factors for each of the three performance metrics. There was no significant difference in correct withhold rate between groups ($t(310) = -.57$, $p = 0.563$) and the corresponding Scaled-Information Bayes Factor of 3.21 (scale $r = 1$; Rouder et al., 2009) supports the null hypothesis. There was no significant difference in omission error rate between groups ($t(306.15) = -.34$, $p = 0.737$) and the corresponding Scaled-Information Bayes Factor of 3.55 (scale $r = 1$; Rouder et al., 2009) supports the null hypothesis. There was no significant difference in reaction time between groups ($t(306.22) = .22$, $p = 0.827$) and the corresponding Scaled-Information Bayes Factor of 3.65 (scale $r = 1$; Rouder et al., 2009) supports the null hypothesis.

Q2. Does trait self-control predict SART performance beyond the speed-accuracy tradeoff? We ran a partial correlation of average correct withhold rate and trait self-control while holding average reaction time constant. The partial correlation of trait self-control and correct withhold rate while holding reaction time constant was partial-r = .28 ($t(52) = 2.09$, $p < 0.05$; see figure 3 below). We used the average for each individual instead of trial-by-trial because correct withholds have no associated reaction time. The reaction time was the average of "go' reaction times or correct responses to neutral stimuli. Correct withhold rate correlated positively to reaction time ($r = .64$, $p < 0.001$) and trait self-control ($r = .25$, $p < 0.05$) Trait self-control did not significantly relate to reaction time ($r = 0.04$, $p > 0.05$).

Figure 3 The relationship between trait self-control and correct withhold rate

Q3. Does the depletion of self-control prior to the SART result in increased perceived stress during the SART? We ran three t-tests to assess the effect of group on the distress, worry, and engagement subscales of the DSSQ. We calculated change values for each participant (i.e. post-test minus pre-test) for these analyses. Since the DSSQ outputs score values and we have two groups, a t-test in the most appropriate method to test this effect. We corrected the critical p-value from .05 to .016 to account for alpha inflation. Study 1 (Satterfield et al 2019) showed that the 'Inhibiting a Natural Impulse' typing task increased the perceived distress experienced during a vigilance task; we wanted to investigate this effect using a motor control task. There was no significant group-based difference in any measure of the DSSQ: worry ($t(46.639) = -1.0677$, $p = 0.29$, Cohen's $d = 0.30$, power = 0.32), engagement ($t(48.306) = -.19$, $p = 0.85$, Cohen's $d = 0.05$, power = 0.06), distress ($t(49.952) = 1.4065$, $p = 0.17$, Cohen's $d = 0.39$, power = 0.50). See table 4 for a summary of DSSQ responses.

Table 4 Summary of DSSQ Change Scores by Condition

Condition	Worry	Engagement	Distress
Control	-.157 (.636)	-.408 (.766)	.797 (.748)
Depletion	.064 (.837)	-.370 (.634)	.510 (.725)

<u>Discussion</u>

The present experiment aimed to answer three questions - (1) *"Does the depletion of self-control prior to the SART result in decreased performance?"*, (2) *"Does trait self-*

control predict SART performance beyond the speed-accuracy tradeoff?", and (3) *"Does the depletion of self-control prior to the SART result in increased perceived stress during the SART?"* We address the results of each of those questions in the sections below. Following those sections, we provide the theoretical and practical implications of our findings and then close with a few concluding remarks and future research ideas.

Trait Self-Control

Our results showed a significant positive relationship between trait self-control and correct withhold rate during the SART. This evidence supports our hypothesis that trait self-control predicts performance on the Sustained Attention to Response Task. Importantly, this effect of trait self-control is likely limited to motor-control/motor-inhibition tasks and does not seem to generalize to traditionally formatted "no-go, go" sustained attention tasks. For example, Becker et al. (2015) found that trait self-control did not predict performance on a traditionally formatted abbreviated vigilance task (Temple et al, 2000). Study 1 (Satterfield et al., 2019) found similar results using the same sustained attention task. The finding that trait self-control predicts the SART and not the traditional vigilance task provides further support to the idea that the SART is qualitatively different than traditional measures of sustained attention (Dang et al., 2018) and that the two tasks cannot be used interchangeably.

Self-Control Depletion

Our results showed no significant effect from the experimental depletion of self-control prior to the SART. This result was surprising, since both the self-control depletion task and the subsequently performed SART both rely on an an inhibition process. We investigated three possible reasons for not detecting an effect on SART performance. First, insufficient power. A power analysis resulted in an observed power of 0.981 (Adj-R2 = .41), which is sufficient to detect a relatively small effect. Second, the 'Inhibiting a Natural Impulse' typing task (Muraven, Shmueli, & Burkley, 2006) may not be strong enough to elicit an effect size of 0.25. However, the self-control depletion task was modelled exactly from previous research that demonstrated a statistically significant effect of the depletion task (Muraven et al., 2006; Rieger, 2004). Moreover, the criterion task used in the Muraven et al. (2006) study was a variant of a traditionally formatted sustained attention task, which makes it even more surprising that no effect was found in the current study. Third, this depletion task may not be as effective at depleting self-control as other depletion tasks (see Hagger et al. 2010 for a review of self-control depletion tasks). Additional research ought to investigate self-control depletion using alternative manipulations, however, we suspect self-control depletion does not affect sustained attention (motor-control or vigilance) in any significant and reproducible way. Perhaps the resource being depleted in sustained attention tasks is not some generalized resource (like self-control) but specific to the task demands themselves. Hence there may be little carryover effect across disparate tasks that utilize different cognitive resources (Helton & Russell, 2015; 2017).

Dundee Stress State Questionnaire

We found no significant difference on the distress, worry, or engagement subscales of the DSSQ between experimental groups. Study 1 (Satterfield et al., 2019) showed that participants who completed the experimental version of the 'Inhibiting a

Natural Impulse' typing task (Muraven, Shmueli, & Burkley, 2006) reported significantly more perceived distress during the abbreviated masked vigilance task than those who completed the control task. Since this effect was not replicated with the SART, we believe that the stress effect may be more closely associated with vigilance tasks than motor control/motor inhibition tasks. Additional work ought to confirm this distinction through replication.

Theoretical Implications

In the SART and similar tasks, as people speed up their responses to stimuli presentations, they are less able to withhold their response appropriately. The speed-accuracy trade-off (SATO) has been considered is the primary determinant of SART performance (Carter, Russell, & Helton, 2013; Dang, Figueroa, & Helton, 2018; Head & Helton, 2013, Helton, 2009; 2010). Motor control tasks require people to break a prepotent motor response which is more frequent than not. The faster a person responds (on average), the less time she has to interrupt the motor response pattern. Past research demonstrates that when people are forced to slow down, they make fewer errors (Muraven et al., 2006). We suspected that people with higher self-control might perform better on the SART due to a strategy shift in the SATO such that people with higher self-control would adopt a convervative response strategy: slowing down to respond more accurately. However, we found that reaction time accounted for little of the covariance between correct withhold rate and trait self-control (Q1), even though reaction time alone shared substantial covariance with correct withhold rate (approximately 41% shared variance). According to our results, trait self-control and reaction time independently affect correct withhold rate in the SART. Indeed self-control shares an additional 6-7% variance with correct withhold rate. People with higher trait self-control outperform those with lower trait self-control seemingly independent of strategy selection (SATO). When combined with past research (Dang, Figueroa, & Helton, 2018), this study provides evidence that vigilance and motor inhibition tasks, specifically the SART, are fundamentally different. Specifically, trait self-control may be a relevant predictor of motor control performance, but not likely a relevant predictor of vigilance performance. Researchers interested in sustained attention research must carefully select and discuss which type of sustained attention task they use in their research.

Practical Implications

According to previous research, accidental friendly fire or 'fratricide' may be more prevalent in a target-rich environment. A series of experiments by Wilson and colleagues (Wilson et al 2015) showed that participants 'fired on friendlies' (using an infrared emitter or 'laser' gun) significantly more often in a target rich environment (89% foes) than in a target-poor environment (11% foes) regardless of if the participants completed a computer based task or in a more ecologically valid scenario (i.e. 'clearing' a physical environment of foes). The participants were undergraduate students with little to no firearm experience, thus limiting the generalizability to trained personnel (i.e. military or police). However, the pattern of behavioral results of the firearm SART used by Wilson and colleagues (2015) suggests that people make more friendly-fire errors in target rich environments while replicating findings regarding signal frequency and the SART. Head and colleagues (2017) demonstrated a similar pattern of findings with trained soldiers. Based on this and our experiment, it is possible that people with higher self-control could be better suited for patrolling and defending target rich environments. We want to make it exceedingly clear that this suggestion linking trait self-control to lower friendly-fire rates is entirely theoretical, has not yet been tested, and should not be acted upon until further research can be conducted.

Limitations

This experiment used a convenience sample from a large mid-atlantic university. While the student population was fairly diverse, the age range was quite limited. There is a chance that the results may not generalize broadly. Military recruits, however, are roughly the same age as undergraduate college students (US Army reported the average age at enlistment was 21; Kokemuller, n.d.) and our findings may affect selection and training as mentioned in section 4.5.

The depletion task had no effect on SART performance. There was a short but irregular delay between the typing task and the start of the SART as the researcher switched programs and started the task. It is possible that the delay may have allowed participants to rest and recover self-control resources differently during the break - if recovery of resources was rapid enough, we may not have seen the effect in the subsequent task performance. Additionally, the task may not have been long or difficult enough to cause a significant difference in performance.

<u>Conclusions</u>

Trait self-control predicts performance on the SART, but not on vigilance tasks, suggesting that trait self-control may be more relevant to motor-control or motor-inhibition tasks than to vigilance tasks. However, trait self-control does predict resource expenditure during a vigilance task (Becker et al., 2015) - those with high trait self-control use fewer resources to complete a vigilance task than those with low self-control. Becker and colleagues (2015) noted that performance on the abbreviated masked vigilance task (12 minutes in duration) began to separate in the final block of the vigil, but that effect was not significant. It's possible that participants with more trait self-control are more efficient with their cognitive resources and the effect may only be detectable in a longer vigil. Future work ought to investigate this possibility.

In the present study, we showed that self-control depletion prior to the SART had no significant effect on performance. However, we did see a significant decrement in performance over time. The resource theory of sustained attention suggests that this decrement in performance over time is due to the depletion of some cognitive resources. However, no study - to our knowledge - has investigated resource consumption during the SART nor the nature of that resource, if it exists. The lack of research in this area is understandable considering that the SART is typically four minutes in duration; thus, the setup of most neurophysiological tools would take longer than the task itself. In the present study, we extended the SART to 12 minutes to match the duration of the abbreviated masked vigilance task used in study 1 (Satterfield et al., 2019). Using the longer SART would allow us to assess the consumption of cognitive resources during the SART and compare it to results reported by Becker and colleagues (2015). This would allow us to determine if the SART uses a cognitive resource similarly to a vigilance task and if that resource consumption was affected by trait self-control as in vigilance tasks (Becker et al, 2015). Further, if the SART depends on a cognitive resource, is it the same resource used in vigilance performance? Future work ought to investigate these remaining gaps in the literature.

CHAPTER FOUR: DO TRADITIONAL VIGILANCE TASKS AND THE SUSTAINED ATTENTION TO RESPONSE TASK USE THE SAME COGNITIVE RESOURCE? - A TRANSCRANIAL DOPPLER INVESTIGATION.

Abstract

Sustained attention research uses two main tasks: traditional vigilance tasks and the sustained attention to response task, which produce conflicting results. For example, performance on the sustained attention to response task depends, in part, on the average speed of response. We suspect that these tasks fall under distinct subcategories of sustained attention. This experiment used a mixed design to test if the two tasks used the same cognitive resource. Participants were randomly assigned to either a control (n=26) or experimental (n=26) condition. Participants in the experimental group completed a traditional vigilance task prior to a twelve minute sustained attention to response task; participants in the control group watched the same traditional vigilance task then completed the same sustained attention to response task. Results suggest that the sustained attention to response depletes a different cognitive resource than traditional vigilance tasks.

Introduction

In an effort to improve safety and efficiency in the real-world, researchers have been investigating potential causes of the vigilance decrement for over the past seventy plus years. Sustained attention tasks require a person to monitor a system for a rare event and respond quickly and accurately. Researchers consistently find that sustained attention performance decreases rapidly in a short period of time (i.e the vigilance decrement; Mackworth, 1948). Several theories regarding the underlying mechanism of action of the vigilance decrement exist; the two most common theories are cognitive resource theory - an overload theory - and mindlessness theory - an underload theory.

The mindlessness theory (i.e. mind wandering theory) of sustained attention states that participants disengage from the task and respond semi-automatically due to the 'monotonous' nature of the task. Despite the sustained attention to response task (SART; Robertson, Manly, Andrade; Baddeley & Yiend, 1997; Manly, Roberston, Galloway & Hawkins, 1999) appearing easy, participants typically have a high error rate and report a high proportion of task-unrelated thoughts (TUT: Smallwood & Schooler, 2006). Helton and colleagues (Dang, Figueroa, & Helton, 2018; Helton, 2009) have shown that participants' who respond faster tend to perform worse (i.e the speed-accuracy tradeoff, SATO); this effect could be caused by the relatively automatic processing of the stimuli combined with the high proportion of 'go' stimuli resulting in a prepotent motor-response pattern. Participants who respond slower have more time to interrupt an incorrect response, thus increasing their overall detection performance (Dang, Figueroa, & Helton, 2018). While the SATO strongly predicts performance, individual differences in performance exist. Harwood and colleagues (under review) found that trait self-control predicted performance beyond the SATO; participants with higher self-control performed better than those with lower self-control. Conceptually, this finding suggests that people with more self-control are better at breaking the motor-response pattern, regardless of their response strategy.

On the other hand, the cognitive resource theory states that sustained attention is mentally demanding and depletes some ‘fuel’ or limited pool of cognitive resources. Research shows that participants who complete a traditional vigilance task (e.g. clock test Mackworth, 1948; abbreviated masked vigilance task, Temple, Warm, Dember, Jones, LaGrange, & Matthews, 2000; TVT) reported high mental demand on the NASA task load index (NASA-tlx; Hart & Staveland, 1988) as performance declined throughout the task (Warm, Parasuraman, & Matthews, 2008). The decrement in performance appears to be related to task difficulty: as event rate increases or signal probability decreases, performance decreases (Parasuraman, 1979). As with the SART, some individual differences affect or predict performance on TVTs (e.g. extraversion, Shaw, Matthews, Warm, Finomore, Silverman & Costa, 2010; Age, Harwood, Greenwood & Shaw, 2017; Review, Finomore, Matthews, Shaw & Warm, 2009).

Despite an apparent fissure between these theories, an examination of sustained attention research suggests that the difference may be attributable to the type of sustained attention task used in the research. The majority of evidence for the mindlessness theory used the SART (Robertson et al., 1997; Manly et al., 1999); the majority of evidence for cognitive resource theory used TVTs. The self-control theory of sustained attention aimed to bridge the gap between these two theories, proposing that self-control is the limited cognitive resource depleted during a sustained attention task (Muraven, Tice, & Baumeister, 1998; Muraven, & Baumeister, 2000). According to this theory, people use self-control to repeatedly redirect their attention to a long-term or high-priority task - monitoring the sustained attention task. Green and colleagues (Green & Rogers, 1995; Green, Rogers, Elliman & Gatenby, 1994) found that dietary restriction results in decreased sustained attention performance. However, the manipulation may have caused more of a distraction from the task (i.e. an issue with selection) rather than poor sustained attention.

Baumeister and colleagues designed the 'inhibiting a natural response' typing task to systematically deplete self-control without manipulating diet and found a significant effect on another self-control based task (Muraven, Shmueli, & Burkley, 2006). However, when using that task to deplete self-control prior to the performance, of the TVT or SART, there was no effect (Satterfield et al 2019; Harwood et al, under review). It is unclear if the typing task did not affect performance on these tasks because (1) the typing task does not deplete self-control, (2) self-control is not the resource vigilance depends on, or (3) the two tasks depend on separate resources entirely. One way to address the confusion would be to assess each potential self-control depletion task's effect on both tasks. However, there are a myriad of self-control depletion tasks discussed in the literature. Iterating through every combination of self-control depletion task and sustained attention task would be prohibitively resource-intensive (i.e time, researcher participants, supplies, etc.).

Instead, the present experiment aimed to address the more fundamental question, "Do the TVT and the SART depend on the same cognitive resource?" while evaluating trait self-control as a potential individual difference in both performance and cognitive resource consumption. One way to answer this question is to use a nuerophysiogoclical tool that has been shown to be reflective of cognitive resource expenditure. When monitoring participants during sustained attention tasks, transcranial doppler sonography (TCD; Stroobant, & Vingerhoets, 2000; Aaslid, 1986) shows a decrement in cognitive resources related to the decrement in sustained attention performance. Specifically, research shows that cerebral blood flow velocity (CBFV) increases in the right hemisphere at the start of the vigil then decreases over time as performance decreases; TCD is sensitive to systematic changes to task difficulty (Warm, Parasuraman, & Matthews, 2008; Shaw, Warm, Finomore, … Parasuramn, 2009; Shaw, Harwood, Satterfield, & Finomore, 2019) and many individual differences (Harwood et al., 2017; Mandell, Becker, VanAndel, Nelson, & Shaw, 2015; Shaw et al; 2016; Shaw et al; 2019). For example, TCD evidence suggests that people with high self-control are more efficient with their cognitive resources over time compared to those with lower self-control, but perform at the same level (Becker, Mandell, Tangney, Chrosniak, & Shaw, 2015).

In this experiment, we used TCD monitoring to assess the effect of cognitive resource depletion prior to and during the SART. Leveraging the findings that simply watching the TVT does not deplete resources (Hitchcock, Warm, Matthews, Dember, Shear, Tripp, ... & Parasuraman, 2003; Helton et al., 2007; Shaw et al., 2009; Shaw, Finomore, Warm & Matthews, 2012), we used the TVT as the depletion task; participants in the experimental condition completed the TVT then the SART while participants in the control condition watched the TVT without a work imperative. If the SART and TVT rely on the same cognitive resource, participants who perform the TVT prior to the SART will perform significantly worse on the SART and show a decrease in available cognitive resources at the start of the task. We continue to investigate trait self-control as a possible individual difference or mechanism of action as a secondary aim of the study; if self-control is the cognitive resource sustained attention relies on, we expect trait self-control scores to be a significant covariate.

Research Questions:

1. Does the effect of trait self-control reported by Harwood et al (under Review) replicate in a new sample?
2. Does the SART deplete cognitive resources? If so, does trait self-control add to the model?
3. Do the TVT and the SART depend on the same cognitive resource? If so, does trait self-control add to the model?

Methods

Participants and Design

This study was approved by the George Mason University Institutional Review Board. Participants gave informed consent and received course credit for their participation. 57 female participants ages 18 to 25 years old with normal or corrected-to-normal vision and were right-handed according to self-report. Participants were not taking any central-nervous system affecting medication (i.e. ADHD medication) and had no history of head injury, concussions or strokes in the 2 years prior to participation according to self-report. Five participants were excluded from the study due to low-quality TCD data (see section 2.4) resulting in a final sample size of 52. For a summary of sample demographics and trait self-control, see table 5. For a summary of the big five personality traits, see table 6.

Table 5 Final Sample Demographics

Condition	N	Age	Education	Trait Self-Control
Control	26	19.9 (2.2)	12.9 (2.7)	118.6 (17.6)
Exp.	26	19.7 (1.7)	13.6 (1.5)	120.7 (16.6)

Table 6 Summary of TIPI Scores by Condition

Condition	Extraversion	Agreeable.	Conscientious.	Emotional Stability	Openness to Experience
Control	7.8 (3.2)	5.8 (2.1)	10.5 (2.2)	7.5 (2.1)	10.4 (2.2)
Exp.	9.1 (2.7)	5.7 (2.0)	11.2 (2.1)	6.8 (2.9)	11.2 (1.7)

Apparatus

Questionnaires. Participants answered a basic demographic questionnaire including age, sex, race, ethnicity, education, medications, sleep habits, caffeine consumption, and other lifestyle information. To assess changes in stress, participants answered the Dundee Stress State Questionnaire (DSSQ; Mathews et al. 1999; 2002) before and after the experiment. To measure trait self-control, participants answered the total self-control scale (Tangney, Baumeister, & Boone, 2004). To assess the Big-Five Personality Traits, participants answered the 10-item Personality Inventory (TIPI; Gosling, Rentfrow, & Swann Jr, 2003). To assess perceived resource availability, participants answered the Gas Tank Questionnaire (Monfort, Graybeal, Harwood, McKnight & Shaw, 2018). These questionnaires were administered digitally.

F.lux Software. In order to maximize the treatment effect, we used the f.lux software blue light filter (version 4.112; 2018) on the testing computer monitor set at a constant 4150K for the duration of the experiment. Blue light interferes with sleep and has an arousing effect because the light elicits similar effects as the sun (Duffy, & Czeisler, 2009). Commercially, the f.lux software has been used in the evening and early morning (i.e when the sun is down) to prevent sleep interference. For this experiment, we used the f.lux software to eliminate the arousing effect of blue light as it would interfere with the fatigue induced by the vigilance tasks.

Traditionally-Formatted Vigilance Task. We used a 12-min abbreviated vigilance task (Temple et al., 2000). The target was the capital letter "O" and non-targets were a forward- and backward-facing capital letter "D". Stimuli were partially masked by a field of small circles in the background. Stimuli were displayed for 40 ms with an interstimulus interval of 1000 ms during which the mask remained. The task was divided into six, two-minute blocks. During each block, there was a total of 120 signals; 20% of the signals were critical (24 critical signals in each block). The task parameters for the TVT were identical to the task used in Chapter 2.

The difference between the experimental and control conditions were the task instructions the participant will receive. Participants in the control condition read the modified task instructions, “Your job is to watch the display until the task stops. You can blink, but otherwise, keep your eyes open for the duration of that task.” Participants in the experimental condition read the normal instructions, “Your job is to press the spacebar when you see the target ‘O’. Do not press anything when you see the ‘D’ or backwards ‘D’. Respond as quickly and accurately as possible.” The instructions in the experimental condition were identical to the instructions used in the vigilance task in Chapter 2.

We ran a pilot study (n=5) with the TVT to determine the appropriate contrast to use for the computer monitor for this experiment. In past experiments, the monitor contrast has been lowered from the standard 50 percent to 30 percent in order for participants to perceive the stimuli without the task being too easy. However, simply setting the monitor’s contrast to 30 may not achieve the desired effect on performance as computer monitor settings vary. All other parameters of this pilot study were identical to the full experiment - specifically, the f.lux blue light filter was active and the lights were dimmed.

The pilot participants completed several two-minute blocks of the TVT. At the end of each two minute round, the program displayed the percentage of correctly identified targets and non-targets. Participants completed the first block with the monitor’s contrast at 20 percent and the monitor contrast was increased or decreased in increments of 5 percent, as appropriate, until the participant's accuracy was 90 percent.

The average contrast level from the pilot participants - 30 percent - was used for the experiment.

Sustained Attention to Response Task. We used a twelve-minute SART (Robertson et al., 1997) identical to the task used in Chapter 3. The program randomly displayed the numbers one through nine. The participants were told to monitor the screen and press the spacebar for all numbers except for the number three. Each signal was presented for 250 ms with an average inter-stimulus interval of 900 ms (range: 750 to 1050 ms). The overall event rate was 52 events per minute with a target event rate of 11 percent (i.e. one in nine). In every two-minute block, each number was randomly presented 12 times. Each block included 12 targets. There was a two-minute long practice. In order to continue, participants were required to detect 90 percent of the targets and commit no more than 10 percent errors in the practice. Participants who failed the practice had a second opportunity to complete the practice. If participants failed two practices, they were thanked and dismissed. These task parameters are identical to those used in Chapter 3.

Transcranial Doppler Sonography. Participants were linked to a functional Transcranial Doppler Sonography unit (Spencer Technologies model PMD150). The unit was equipped with two 2 MHz pulsed transducers embedded in a plastic bracket that was secured around the head with an adjustable Velcro strap. Both the left and right transducers were placed along the temporal bone dorsal and immediately proximal to the zygomatic arch. Ultrasound transmission gel was placed between each TCD transducer and the participant's skin to obtain a clear ultrasound signal. CBFV was measured from the mainstream middle cerebral arteries (MCAs) for the left and right cerebral hemispheres and provide a reading in cm/sec. The MCAs were monitored at approximate depths of 50-55 mm. Researchers monitor the MCAs during sustained attention tasks because it supplies about 80% of the blood to the brain (Stroobant & Vingerhoets, 2000). Participants were told to look at a white screen with a black fixation cross for five minutes to provide a baseline for the TCD - the last 60 seconds was used as the baseline index, consistent with previous research (Aaslid, 1986; Shaw et al. 2009). Becker and colleagues (2015) - discussed previously - utilized the TCD and followed an identical baseline protocol.

Procedure

Prior to the participants' arrival, the researcher turned on the f.lux blue light filter on the computer, verified the contrast was set to 30 percent, dimmed the lights, and assigned the participants' condition. Upon arrival, participants were greeted and shown to a windowless laboratory. The participants gave informed consent. The participants then completed a set of questionnaires: the Gas Tank Question, demographics, trait self-control, TIPI, and the pre-experiment DSSQ survey, in that order. The researcher set up the TCD machine, then the participant completed the baseline protocol. The participant completed a two-minute practice of their assigned TVT task and the SART task, repeating each practice if necessary. A second baseline was taken for 2 minutes. The participant completed the Gas Tank Question a second time, the main trials of their assigned TVT, the main trials of the SART, and, finally, the Gas Tank Question a third time. The TCD unit was turned off and removed. Participants completed the post-experiment DSSQ and a brief post-experiment survey. The entire experiment lasted between 90 and 120 minutes depending on the duration of the TCD setup.

Data Analysis

We assessed participants' survey reports for study eligibility criteria and removed those who did not qualify. We pre-processed and analyzed the TCD data for poor data quality and extreme outliers - five participants were removed. The data for each sustained attention task was divided into 6 equal time blocks of approximately two-minutes - congruent with the behavioral data analysis plan. For each participant in each time block, we calculated the mean standard deviation of cerebral blood flow velocity (CBFV) for the left and right middle cerebral arteries (MCAs). The means were then converted to a metric known as percent over baseline - this procedure has been used in previous experiments and is the current standard for TCD analysis in Neuroergonomics (Harwood, Satterfield, & Finomore, 2019). Each participant's mean CBFV for each time block was divided by the left or right mean CBFV in the last 60 seconds of the second baseline period.

The quality of the data was determined using the standard deviations of cerebral blood flow velocity (CBFV) for the left and right middle cerebral arteries (MCAs) during each time block, for each participant. We removed participants who had standardized standard deviations more than 3 standard deviations from the mean nested within the condition and task - 3 from the vigilance task and 3 from the SART. One participant had poor data quality in both tasks. In each case, the research assistant associated with these participants noted concern over data quality in the experiment log. A total of 5 participants were removed for poor TCD data quality from the entire study. The quality check for TCD data was performed prior to any analysis or computation of descriptive statistics for the behavioral data in order to prevent bias from influencing the researchers' decision.

Results

Where appropriate, greenhouse-geisser corrections have been applied to all analysis of variance (ANOVA) models. For the ANOVAs examining the effect of block, we report the main effect as well as trend analyses. Analyses were conducted using R (version 3.6.1; Ihaka, & Gentleman, 1996; Team, 2018) and various packages: afex (version 0.25-1; Singmann, Bolker, Westfall, & Aust, 2015), emmeans (version 1.4.1; Russell, 2018), and tidyverse (version 1.2.1; Wickham, 2017).

Manipulation Check

In order to test if the experimental participants had a vigilance decrement during the TVT, we checked for (1) a performance decrement over time, and (2) a right-lateralized CBFV decrement over time, consistent with previous literature.

The one by six (block) repeated measures ANOVA evaluating correct detection rate during the TVT was conducted. The main effect of block was significant ($F(3.14,78.46) = 25.05$, $p <0.001$, $\eta p2 = 0.50$). Test of orthogonal contrast revealed a linear tread for block ($F(1,25) = 54.81$, $p < 0.001$). Preplanned comparison revealed that correct detection rate decreased from block 1 to blocks 3 through 6 ($p = 0.0001$, 0.0001, 0.0001, & 0.0001, respectively), from block 2 to blocks 3 through 6 ($p = 0.025$, 0.0001, 0.0001, & 0.0001, respectively), from block 3 to blocks 4 through 6 ($p = 0.025$, 0.003, &

0.0001, respectively), and from block 4 to block 6 ($p = 0.006$). For means and standard errors, see table 3. When entered as a covariate, trait self-control did not significantly contribute to the model.

Table 7 Traditional Vigilance Task Performance Metrics by Block for the Experimental Task Only.

Performance Metric	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Correct Detections	97.9 (0.8)	94.1 (1.6)	89.3 (2.1)	84.5 (2.5)	81.4 (2.8)	78.5 (2.6)
False Alarms	2.40 (0.50)	1.49 (0.31)	1.41 (0.35)	2.29 (0.42)	2.25 (0.60)	2.61 (0.65)
Reaction Time	456.07 (9.02)	495.21 (12.33)	516.74 (10.21)	532.76 (11.48)	539.74 (10.27)	553.73 (11.90)

We conducted a 2 (condition) by 2 (hemisphere) by 6 mixed ANOVA evaluating CBFV during the TVT. The main effect of block was significant ($F(3.44,171.77) = 8.34$, $p < 0.0001$, $\eta_p^2 = 0.14$). Test of orthogonal contrast revealed a linear trend for block ($F(1, 50) = 16.53$, $p < 0.0001$, $\eta_p^2 = 0.25$). There was a main effect of hemisphere ($F(1,50) = 23.05$, $p < 0.0001$, $\eta_p^2 = 0.32$). There was not a significant main effect of condition ($p = 0.43$), nor a condition by block ($p = 0.26$) or condition by hemisphere, $p = 0.15$) interaction. There was a significant cubic hemisphere by block interaction ($F(1,50) = 5.521$, $p = 0.023$, $\eta_p^2 = 0.099$). There was a significant linear three way interaction ($F(1, 50) = 4.87$, $p = .032$, $\eta_p^2 = 0.089$), such that CBFV was significantly higher in the experimental group's right hemisphere than the control group's right hemisphere in blocks 1 ($p = 0.024$) and 2 ($p = 0.033$), but not blocks 3 through 6. When entered as a covariate, trait self-control did not significantly add to the model. For a visual representation of the three-way interaction, see figure 4.

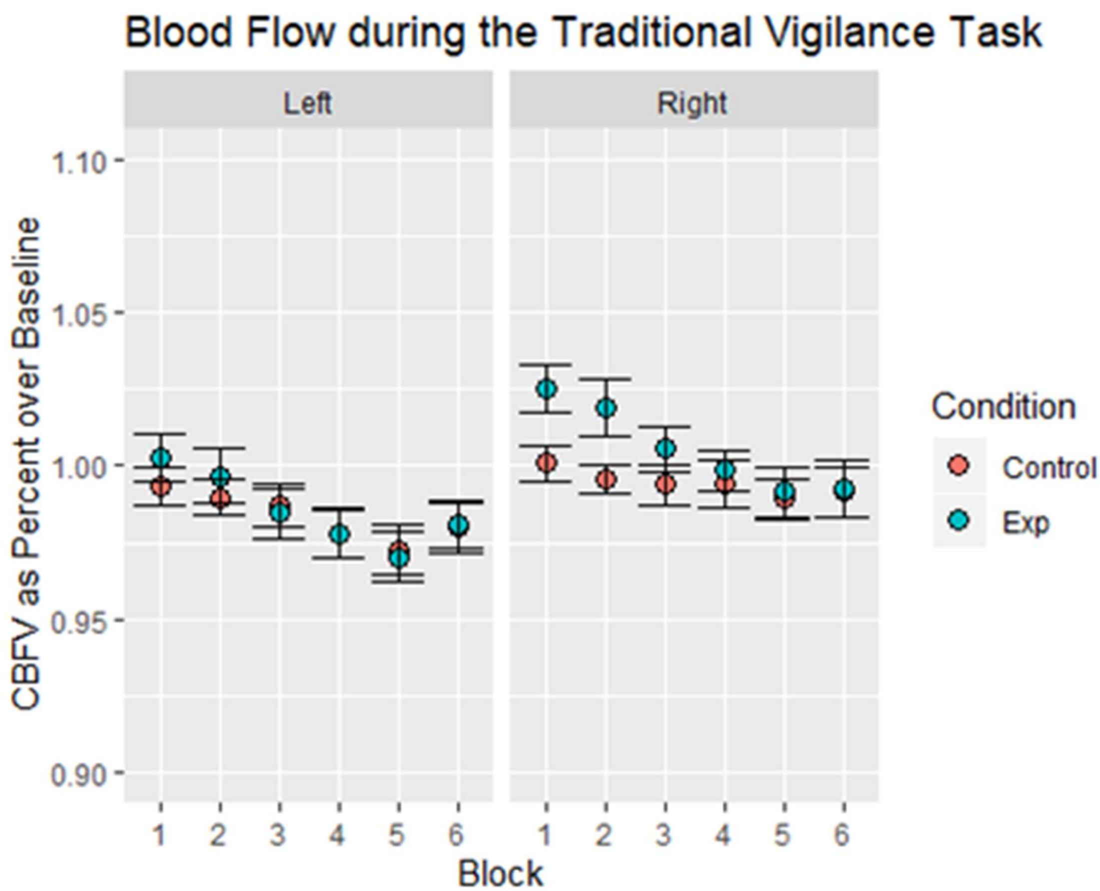

Figure 4 Change in CBFV over time by hemisphere for the experimental group

We concluded that the experimental group's performance and CBFV followed the expected pattern for sustained attention research. There was a significant performance decrement during the TVT and an initial increase in CBFV followed by a decrement in the right hemisphere. The control group did not show a right lateralized CBFV pattern.

Research Questions

Replication. This study was a direct follow-up to prior research (Harwood et al, under review). One goal of this experiment was to see if the prior finding replicated in a new sample - that trait self-control predicted overall correct withhold rate beyond the speed accuracy trade-off. To test this, we used the same analysis as Harwood and colleagues (under review): a partial correlation of average correct withhold rate and trait self-control while holding average reaction time constant. The partial correlation was not significant (partial-r = -0.05, p = 0.75). Correct withhold rate correlated positively to reaction time (r = .74, p < 0.001), but not trait self-control (r =.11, p = 0.43). Trait self-control did not significantly relate to reaction time (r = 0.19,p = 0.17). This evidence does not support the replication of the previous experiment.

Performance on the SART. To test if there was a performance difference between the two conditions during SART, we ran a two (condition) by six (block) repeated measures ANOVA evaluating correct withhold rate during the SART using average 'go' reaction time as a covariate. There was a significant effect of block (F(3.95,193.44) = 3.51, p = 0.009, ηp2 = 0.07). The covariate reaction time was significant (F(1,49) = 60.15, p <0.001, ηp2 = 0.55). Test of orthogonal contrast revealed a linear tread for block (F(1,49) = 9.257, p = 0.004). There was no significant main effect of condition (p = 0.66) nor a block by condition interaction (p = 0.59). Preplanned comparison revealed that correct detection rate decreased linearly from block 1 to blocks 2 through 6 (p = 0.0019, 0.0001, 0.0001, 0.0001, & 0.0001, respectively), from block 2 to blocks 5 and 6 (p = 0.0055, & 0.0001, respectively), from block 3 to block 6 (p =

0.0019), and from block 4 to block 6 (p = 0.0266). Scaled JZS Bayes Factors were calculated to see if the condition factor for each block was null or simply non-significant: 3.46, 3.51, 3.59, 2.40. 2.02, and 3.52, respectively. Each of these bayes factors were in favor of the null hypothesis (Rouder, Speckman, Sun, Morey, & Iverson, 2009). For means and standard errors, see table 8. When entered as a covariate, trait self-control did not significantly add to the model.

Table 8 Sustained Attention to Response Task Performance Metrics by Block and Group.

Condition	Performance Metric	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Control	Correct Withholds	66.0 (4.31)	59.0 (4.98)	56.1 (5.58)	50.6 (4.87)	47.4 (5.31)	48.4 (6.22)
	Omission Errors	2.44 (0.71)	2.81 (1.16)	3.45 (1.20)	4.49 (1.38)	4.21 (1.30)	4.77 (1.17)
	Reaction Time	361 (13.6)	378 (15.7)	370 (19.6)	376 (19.4)	388 (20.4)	388 (20.0)
Exp.	Correct Withholds	64.4 (4.25)	53.8 (4.29)	51.9 (4.17)	52.2 (3.99)	49.7 (4.79)	42.0 (4.81)
	Omission Errors	2.44 (0.45)	1.64 (0.48)	2.73 (0.78)	2.29 (0.43)	2.41 (0.41)	3.25 (0.73)
	Reaction Time	360 (12.6)	358 (12.4)	357 (11.7)	359 (12.4)	355 (11.5)	359 (14.2)

Resource Consumption during the SART. To test if there was a difference in resource consumption between the conditions on the SART, we ran a 2 (condition) by 2 (hemisphere) by 6 (block) mixed ANOVA evaluating CBFV (relative to baseline) during the SART using trait self-control as a covariate. There was a significant effect of block ($F(3.77,188.62) = 8.41$, $p < 0.0001$, $\eta p2 = 0.14$). Test of orthogonal contrast revealed a linear tread for block ($F(1,49) = 7.838$, $p = 0.007$, $\eta p2 = 0.31$). There was a significant main effect of hemisphere ($F(1,50) = 7.84$, $p = 0.007$, $\eta p2 = 0.14$), such that the right ($M = .999$, $se = .002$) was higher than the left ($M = .987$, $se = .002$). There was not a main effect of condition ($p = 0.23$). There was a marginal condition by hemisphere interaction ($F(1,50) = 3.40$, $p = 0.07$). There was a significant linear block by hemisphere interaction ($F(1,50) = 4.19$, $p = 0.046$, $\eta p2 = 0.077$), and a significant quadratic three-way interaction ($F(1,50) = 2.36$, $p = 0.05$, $\eta p2 = 0.075$), such that CBFV was significantly higher in the control group's right hemisphere than the experimental group's right hemisphere in blocks 1 ($p = 0.038$) and 2 ($p = 0.028$) but not in blocks 3 through 6 - see figure 5. For means and standard error, see table 9. When entered as a covariate, trait self-control did not significantly add to the model.

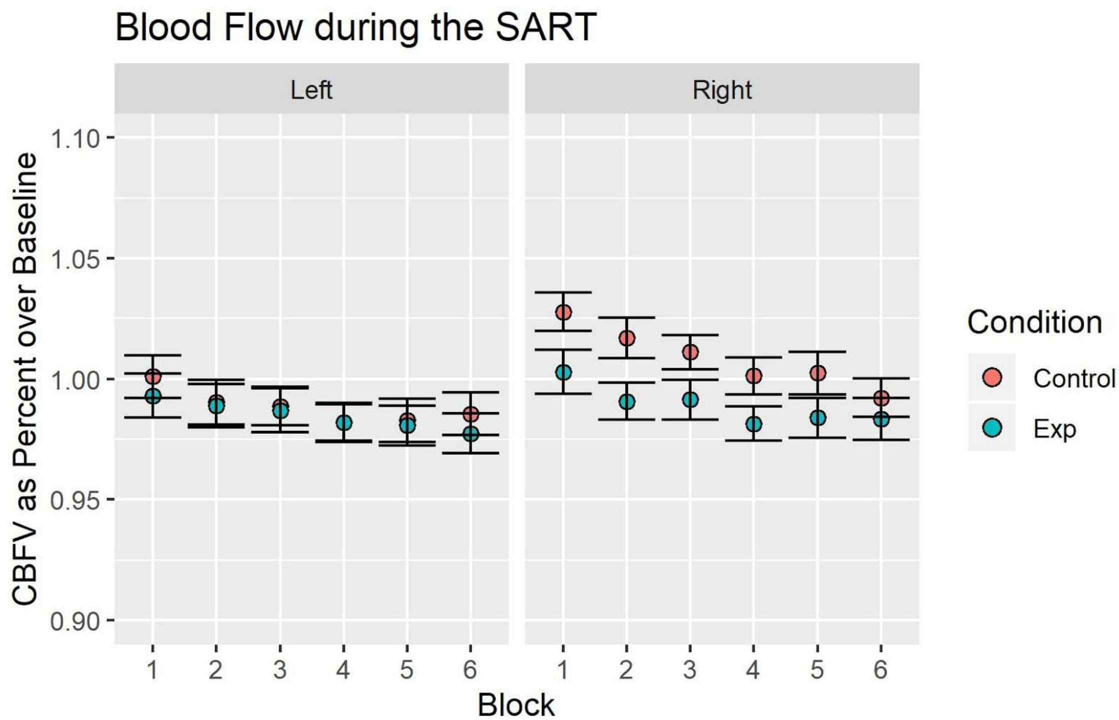

Figure 5 Change in CBFV over time by hemisphere for the experimental group

Table 9 Sustained Attention to Response Task Performance Metrics by Block and Group.

Condition	Hemisphere	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Control	Left	1.00 (.009)	.990 (.009)	.989 (.008)	.982 (.008)	.983 (.009)	.986 (.009)
	Right	1.03 (.008)	1.02 (.008)	1.01 (.007)	1.00 (.008)	1.00 (.009)	.992 (.008)
Exp.	Left	.993 (.009)	.989 (.009)	.987 (.009)	.982 (.008)	.981 (.008)	.984 (.008)
	Right	1.00 (.009)	.991 (.008)	.991 (.008)	.982 (.007)	.984 (.008)	.983 (.009)

Dundee Stress State Questionnaire

To assess the effect of the experiment on the three primary outcomes of the DSSQ (i.e. worry, distress, and engagement), we conducted three 2 (condition) by 2 (phase;

pre/post) repeated measures ANOVAs evaluating each construct. The ANOVA for worry revealed no main effect of phase ($p = 0.74$), condition ($p = 0.41$), nor an interaction ($p = 0.77$). The anova for distress revealed a marginal effect of time ($F(1,98) = 3.792$, $p < 0.0544$, $\eta p2 = 0.037$), but not condition ($p = 0.33$) nor an interaction ($p = 0.63$). The anova for engagement revealed a significant effect of phase ($F(1,98) = 6.25$, $p < 0.001$, $\eta p2 = 0.095$), but not condition ($p = 0.23$) nor an interaction ($p = 0.56$). Taken together, this suggests that the experiment caused decreased engagement from before the experiment and after the experiment. For a summary of the three primary outcome variable by phase and condition, see table 10 below.

Table 10 Summary of DSSQ Scores by Condition and Phase

Condition	Phase	Worry	Engagement	Distress
Control	Pre	0.710 (0.262)	-0.363 (0.161)	0.216 (0.141)
	Post	0.586 (0.265)	0.319 (0.148)	-0.604 (0.169)
Exp.	Pre	0.938 (0.261)	-0.377 (0.206)	0.448 (0.141)
	Post	1.070 (0.296)	0.374 (0.203)	-0.043 (0.153)

Gas Tank Questionnaire

A two (condition) by three (timepoint) mixed ANOVA was conducted on the Gas Tank Questionnaire (GTQ), which evaluates the perceived availability of cognitive resources (Monfort et al 2017). The GTQ data was collected prior to the TVT, after the TVT, and after the SART. There was a main effect of timepoint ($F(1.85,92.37) = 57.95$, p

< 0.0001, $\eta p2 = 0.54$), such that perceived available resources declined over time. There was no main effect of condition ($p = 0.79$) nor a timepoint by condition interaction ($p = 0.44$). Preplanned comparisons revealed that gtq score for the control group were not significantly different from before the experiment to after completion of the TVT ($p = 0.21$), but was significantly different from before the experiment to after completion of the SART ($p < 0.0001$) and from after the TVT to after the SART ($p < 0.0001$). For the experimental group, there was a significant difference from pre-experiment to post-TVT ($p = 0.02$), from pre-exp to post-SART ($p < 0.0001$) and from post-TVT to post-SART ($p < 0.0001$). Scaled JZS Bayes Factors were calculated to see if the condition factor for each block was null or simply non-significant: 3.58. 2.61, and 3.43, respectively. Each of these bayes factors were in favor of the null hypothesis (Rouder, et al., 2009). For descriptive statistics of GTQ scores, see table 11.

Table 11 Summary of GTQ Scores by Condition and Timepoint

Condition	Pre-Exp	After TVT	After SART
Control	0.64 (0.03)	0.59 (0.03)	0.38 (0.04)
Exp.	0.63 (0.03)	0.55 (0.03)	0.40 (0.04)

Discussion

We aimed to address several questions in this experiment. Below, we discuss the results relevant to each question. Then we discuss the theoretical and practical implications, as well as how the results of this experiment fit into the existing literature on sustained attention.

Replication of Study 2

One goal of this experiment was to see if the main result from Harwood et al (under review) was replicable. The previous experiment found that trait self-control was positively related to correct withhold rate (partial r = 0.28) during the sustained attention to response task (SART) after accounting for the variance associated with response time (i.e. the speed-accuracy tradeoff; SATO). We conducted a partial correlation analysis that was identical to the previous experiment as well as individual correlations between each metric. While we found that reaction time was positively related to the correct withhold rate, the partial correlation for trait self-control was not significant (partial r = -0.05). Thus, this experiment replicated the SATO effect, but not the effect of trait self-control. Both experiments sampled from the same university, at different times. However, the previous experiment reported a mean trait self-control score of approximately 100 while this sample had a mean trait self-control score of 119.52. Given that the possible scores on the scale range from 36 to 180 (Tangney et al., 2004), we suspect that the effect of trait self-control may be nonlinear - affecting those with lower self-control scores, but not those with higher self-control scores. Further research should aim to recruit a sample of participants with a larger range of trait self-control than the present experiment.

Does the SART deplete cognitive resources?

Secondly, we wanted to test if participants deplete cognitive resources during the SART in a similar manner to traditional vigilance tasks (e.g Warm et al., 2008; Mandel et al., 2015). To answer this question, we examined the performance and cerebral blood flow velocity (CBFV) data for just the control participants during the SART. Control participants showed a decrease in performance over time consistent with previous research (Robertson, et al., 1997; Manly, et al., 1999) and more traditional vigilance experiments (Mackworth 1948; Warm et al., 2008). Additionally, control participants' CBFV data showed an initial increase in blood flow to the right hemisphere which then declined over time and returning to baseline. These CBFV results are consistent with the CBFV results of previous experiments that used a TVT (e.g. Shaw et al; 2016; Shaw et al; 2019). Based on the performance and CBFV results, we believe that the SART does drain some cognitive resources, like a TVT.

Do the TVT and the SART depend on the same cognitive resource?

We designed this experiment to test if performing the TVT prior to the SART affects performance, cognitive resource availability, or both during the SART compared to a group that simply watched the TVT without a work imperative. This type of control group was used in some of the classic experiments investigating the cognitive resource theory of vigilance (Warm et al., 2008). If the two tasks rely on and deplete the same cognitive resource, we expected the experimental group to perform worse on the SART and have fewer resources available at the start of the task, compared to the control group. We found that participants in both conditions had a decrement in performance over time, but there was no difference between conditions, but there was the expected pattern in CBFV. Participants in the control condition had higher CBFV in the right hemisphere than the experimental group at the start of the task. This evidence suggests that participants in the experimental condition depleted their cognitive resources during the TVT and were unable to devote additional resources to the SART, particularly at the start of the task. Ideally, we would have seen a difference in performance related to the poverty of cognitive resources available to the experimental group during the TVT. Without a decrement in performance, we conclude that the SART depletes cognitive resources independent of that depleted in the TVT.

Self-reported perception of resource availability (i.e gas tank questionnaire) showed that participants in the control condition reported decreased resource availability during the SART only while the experimental condition reported decreased resources during both tasks. Interestingly, there was no significant difference between the conditions at any given timepoint. Additionally, participants in both conditions reported a negative change in engagement during the experiment, as is typical of sustained attention tasks (Mathews et al. 1999; 2002). Thus, participants in both groups had equivalent subjective experiences while performing at the same level over time. However, there was an initial increase in CBFV for the experimental condition during the TVT and the control condition during the SART, as expected. This evidence does not suggest that the TVT and the SART depend on the same cognitive resource, but that they both affect the participants' perception of available cognitive resources. Perhaps, participants are unable to differentiate multiple resources when reporting available resources, despite abundant evidence suggesting different cognitive processes use different pools of cognitive resources (Wickens, 2002).

Theoretical Implications

Trait self-control, as measured here, may not reliably predict performance or cognitive resource efficiency on either type of sustained attention tasks. Harwood et al (under review) showed that trait self-control predicted performance on the SART beyond the speed-accuracy tradeoff, but the effect was not replicated in the current experiment. As noted previously, the two samples had a different range of self-control scores; it's possible that trait self-control has a non-linear effect on SART performance. Alternatively, the original find may have been a false positive. Similarly, Becker and colleagues (2015) showed that trait self-control predicted resource efficiency during a TVT (although there was no performance difference in that study either), but that effect did not replicate in the present experiment. Additionally, two studies looked at the effect of self-control depletion on performance during both types of sustained attention tasks (TVT, Satterfield et al 2109; SART, Harwood et al, under review) - in both cases, self-control depletion had no effect on performance. The present experiment showed that the SART depends on cognitive resources, but that self-control does not predict resource efficiency. Given this accumulation of evidence (Becker et al., 2015, Satterfield et al, 2019, Harwood et al, under review), the self-control theory of vigilance (Muraven, Tice, & Baumeister, 1998; Muraven, & Baumeister, 2000) is flawed, if not wholly inaccurate. If self-control were the cognitive resource that sustained attention depends on, we would find consistent and large effects of self-control on sustained attention performance or cognitive resource consumption. At best, trait self-control, as measured here, may be an individual difference of interest in sustained attention research that appears to be inconsistent or non-linear.

It should be noted that recent work has revealed multiple facets of self-control. De Ridder and colleagues (2011) theorized a two factor model of self-control - inhibitory and initiatory self-control. This two factor model may be more appropriate that a generic self-control measure for research on sustained attention. The TVT is an excitatory task which may be more closely related to the initiatory factor of self-control; The SART is an inhibitory task which may relate more closely to the inhibitory self-control factor. Here, self-control was measured with the 36-item total self-control scale while the two-factor model of self-control was validated using the 13-item brief self-control scale (Tangney et al 2004; De Ridder et al., 2011). While the items used in the brief scale are included in the full scale, we did not attempt to recreate the two-factor model in the present experiment. Future research ought to investigate the two-factor model of self-control as it related to sustained attention by using the 13-item scale in new research or validating the two-factor model with the 36-item scale and re-analyzing existing data.

What if transcranial doppler findings do not represent what we think it does? Research using TCD consistently reveals an initial increase in blood flow to the right hemisphere at the beginning of a sustained attention task followed by a decrease over time similar to the decrement in performance. Shaw and colleagues (Harwood et al., 2017; Mandell, Becker, VanAndel, Nelson, & Shaw, 2015; Shaw et al; 2016; Shaw et al; 2019) consistently interpreted TCD results as a measure of resource consumption during sustained attention; deviations from the typical right lateralized pattern have been associated with individual differences in age (Harwood, Greenwood & Shaw, 2018), extraversion (Shaw, Nguyen, Satterfield, Ramirez, & McKnight, 2016), expertise (Shaw, Satterfield, Ramirez, & Finomore, 2013b), and many more. In the absence of performance differences, differences in TCD results have been interpreted as one group (i.e experts) being more efficient with their cognitive resources than another group (i.e novices). In the present experiment, the control group watched the TVT then performed the SART whereas the experimental group performed the TVT and then the SART. The experimental group showed the typical CBFV pattern during the TVT, but - as expected - the control group did not. During the SART, the control group showed the typical CBFV pattern, but the experimental group did not. If the experimental group performed worse on the SART, we would say that the TVT fatigued the experimental group, but the two groups performed equivalently. In fact, we believe this shows that the two tasks do not depend on the same cognitive resource.

Practical Implications

Consistent with previous research (Dang, Figueroa, & Helton, 2018), this experiment showed that participants who responded slower on average tended to be more accurate (i.e. speed-accuracy tradeoff). Training participants to slow down to prioritize accuracy could reduce errors of commision. Previous research showed that ‘friendly fire” rates may also be subject to a SATO in undergraduate participants (Wilson et al., 2015) and trained soldiers (Head et al, 2017). Perhaps, training soldiers to slightly slow their reaction time could reduce “friendly fire” or civilian casualties, without letting the enemy wound or kill more soldiers.

Limitations

This experiment used a convenience sample consisting of undergraduate students enrolled in psychology courses. The sample size, while sufficient for within subject neurophysiological analyses, may not have been sufficient to test the relationship a personality trait with performance or neurophysiological data. As previously mentioned, the relationship between trait self-control and sustained attention may be non-linear. Future research ought to use a larger sample with a wider range of self-control scores.

CHAPTER FIVE: GENERAL CONCLUSION

Throughout this line of research, we investigated the effect of trait and state-based self-control on the two most common vigilance tasks. The research presented in chapter two (Satterfield, Harwood, Helton, & Shaw, 2019) showed that self-control depletion had no effect on performance during a traditional vigilance task, but increased the perceived distress experienced by the participants. The research presented in chapter three (Harwood, Satterfield, Helton, McKnight, & Shaw, under review) showed that self-control depletion had no effect on performance on the sustained attention to response task. The self-control depletion task was used as a means of depleting the self-control resource pool in previous research (Muraven et al. 2006, Rieger, 2004), and affected performance on future tasks that require self-control. Despite using a previously validated self-control depletion task, it is possible there were subtle differences in the procedure used by the original researchers and the research presented in chapters two and three. Combined with the short but variable time between the end depletion task and the start of the sustained attention tasks, participants had a short rest – during which cognitive resources may have replenished. In fact, Helton and Russell (2015) reported that rest improves sustained attention performance over alternative mitigation strategies. Since researchers have not determined how long self-control resources take to replenish, the variable break between the self-control depletion manipulation and the sustained attention task may have introduced random variance into the experimental design, reducing the likelihood of detecting an effect. The sustained attention tasks were also relatively short – twelve minutes – compared to real-world vigilance tasks; perhaps the effect of self-control is larger as the vigil continues. Given these considerations, further research may consider investigating self-control depletion with precisely controlled and minimal rest prior to the sustained attention task, longer sustained attention tasks, and/or more extreme depletion manipulations. There are a multitude of self-control depletion tasks discussed in the literature that may be more closely related to sustained attention – increasing the duration of the self-control depletion typing task may also enhance the manipulation.

Trait self-control may have a small or nuanced relationship with sustained attention tasks. With a traditional vigilance task, trait self-control does not relate to performance (chapter 2; Becker et al 2015) but does predict resource allocation. Becker and colleagues (2015) showed that transcranial doppler sonography (TCD) reveals differences between individuals high in trait self-control than with low trait self-control; participants with high self-control had better resource allocation strategies, but not superior performance than participants with low self-control. Research using the sustained attention to response task is less clear. The research presented in chapter three show that trait self-control predicted performance beyond the speed-accuracy tradeoff; those with higher self-control tended to perform better throughout the task. However, the research in chapter four aimed to replicate the finding in chapter three - that trait self-control predicted performance beyond the speed-accuracy tradeoff - but the effect did not replicate. The failure to replicate the findings may be caused by a difference in the range of trait self-control sampled in the two experiments, as previously discussed.

Sustained attention relies on an unknown cognitive resource; it is possible that different types of sustained attention takes rely on different resources. The research presented in chapter four (Harwood, Helton, McKnight, Johnson, & Shaw, in prep) showed that the traditional vigilance task and the sustained attention to response task both deplete cognitive resources, as measured by TCD. However, there was no decrement in performance during the sustained attention to response task in participants who completed the traditional vigilance task compared to those who simply watched the traditional vigilance task. At the start of the traditional vigilance task, only the experimental group showed the right lateralized blood flow pattern associated with sustained attention performance, as expected. At the start of the sustained attention to response task, the control group showed the typical blood flow pattern, as expected. Interestingly, the experimental group still showed a slight increase in blood flow in the right hemisphere, but to a lesser degree than the control group. This evidence suggests the experimental group had some additional resources to devote to the sustained attention to response task, but less than they had available at the start of the traditional vigilance task. The cognitive resource theory of sustained attention posits a *single* unknown cognitive resource, but these results may suggest that the two types of vigilance rely on either different cognitive resources or sustained attention tasks rely on multiple resources.

If sustained attention tasks rely on multiple resources, perhaps the two types of tasks require a different amount of resources, at different stages of processing. For this conceptualization, we use the Multiple Resource Theory framework (Wickens, 2008). Both types of sustained attention tasks used in this line of research required participants to respond to alpha-numeric stimuli presented in the focal, visual field. As previously discussed, the stimuli used in the traditional vigilance task are perceptually difficult to identify; the stimuli used in the sustained attention to response task are clear and relatively easier to perceive. Consistent with the speed-accuracy tradeoff literature, the difficulty with the sustained attention to response task may be primarily during the response stage as the participant must over-come the prepotent motor response pattern developed in 'high-go' tasks like the sustained attention to response task. In contrast, the primary difficulty in a traditional vigilance task may be in the perception stage (i.e. identifying the target) but not as much during the response stage. Thus, sustained attention tasks as an overarching category many require multiple resources to complete with different tasks utilizing a different ratio of these resources. This conceptualization of multiple sustained attention resources has not been tested; we discuss it here as a possible explanation for the behavioral and neurophysiological results reported in chapter four.

This line of research suggests that the effect of trait self-control on the sustained attention to response task may be more nuanced than originally theorized by Baumeister and colleagues (Muraven & Baumeister, 2000). We suspect that the effect of trait self-control may be non-linear; self-control helps sustained attention at the lower end of the scale, but as self-control increases, the returns diminish. The previous statement is purely speculative based on the available evidence in the present experiment - future research ought to investigate this claim. Based on chapter four, we now suspect that the sustained attention to response task depletes cognitive resources similar to, but independent of, the traditional vigilance tasks. This line of research provided additional evidence for the cognitive resource theory of sustained attention in both types of sustained attention tasks and replicated the speed-accuracy tradeoff effect in motor-inhibition tasks. However, this work cannot definitively conclude if self-control is – one of – the resource(s) that sustained attention task performance depends on. Future research ought to investigate the relationship of alternative measures of trait self-control and sustained attention performance as well as potentially using longer sustained attention tasks. Alternate methods of self-control depletion may have stronger, more consistent effects on sustained attention performance: these ought to be investigated.

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