EFFECTS OF SELF-CONTROL TRAINING AND BRAIN ENDURANCE TRAINING ON ENDURANCE PERFORMANCE AND RATINGS OF PERCEIVED EXERTION

EFFECTS OF SELF-CONTROL TRAINING AND BRAIN ENDURANCE TRAINING ON ENDURANCE PERFORMANCE AND RATINGS OF PERCEIVED EXERTION

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Abstract

Self-Control Training (SCT) and Brain Endurance Training (BET) are novel training modalities designed to enhance physical endurance by building fatigue resiliency. Despite their similarities, it has yet to be examined whether combining SCT and BET provides an additive or redundant/overlapping effect on endurance exercise performance. This study investigated the effects of SCT and combined SCT+BET on performance of a maximal exertion isometric resistance endurance task (high plank) and ratings of perceived exertion (RPE). Participants (N = 33) were randomized to engage in 4 weeks (18 training sessions) of SCT (isometric handgrip; n = 13), SCT+BET (10-minute cognitively demanding task, followed by SCT; n = 10), or no-training/control (n = 10). Isometric endurance performance trials were completed at pre-, mid-, and post-training. One-way analysis of covariance (ANCOVA) models were computed for each of the mid- and post-training trials (controlling for pre-training high-plank performance) to assess effects on performance. Results showed no significant effects of training on high plank performance between groups at mid-training; however, a large and significant effect for SCT compared to control was observed at post-training (p = .044, d = .961). No significant main effects or interaction effects were found for changes in RPE over time (p's > .05). Findings support the use of SCT as an effective training method for physical endurance performance and suggest that BET may not offer additional performance benefit compared to SCT under the training and testing conditions used in this protocol. Future research should explore potential dose-response effects of SCT on performance and moderators such as trait self-control.

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List of Abbreviations

AB	(sequential task paradigm design)
ABA	(sequential task paradigm design)
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
AX-CPT	AX- Continuous Performance Test
BET	Brain Endurance Training
CR-10	Category Ratio – 10
fNIRS	functional Near Infrared Spectroscopy
GXT	Graded Exercise Task
ID	Identification
IPAQ	International Physical Activity Questionnaire
MF-VAS	Mental Fatigue - Visual Analogue Scale
MVC	Maximal Voluntary Contraction
MVPA	Moderate to Vigorous Physical Activity
NPT	Neuro Performance Technology
PAR-Q	7-day Physical Activity Recall Questionnaire
PET	Precision Effect Test
PEESE	Precision Effect Estimation with Standard Error
RPE	Ratings of Perceived Exertion
SCT	Self-Control Training
SCT+BET	Self-Control Training + Brain Endurance Training
SD	Standard Deviation

SE	Standard Error
TLDB	Time Load Dual Back
TM	Trademark
TTF	Time Till Failure

Declaration of Academic Achievement

I, Daniel Trafford, declare that I am the lead author of this thesis. My responsibilities included creating and amending the ethics application, designing the study protocols, carrying out data collection procedures (i.e., participant recruitment, running online sessions, etc…), supervising volunteers assisting with data collection, conducting all data analyses, as well as preparing the manuscript. All work was completed under the supervision of Dr. Steven Bray who provided input and feedback regarding the ethics application, study design, study measures, data interpretation and manuscript preparation.

Introduction

Self-control and Ego Depletion

Self-control refers to: "everything that one *does* to steer one's behaviour towards [their] desired end state" (Gillebaart, 2018). Self-control is so pervasive, it has been claimed that every effortful or effortless, deliberate or automatic, inhibitory or initiatory actions made to direct or alter an individual's behaviour towards a desired outcome or end state requires self-control (Baumeister & Vohs, 2003; Gillebaart, 2018). Thus, self-control is part of the process whenever an individual pursues goals or tasks that require inhibition of habitual or well-learned responses, delayed gratification (e.g., pushing through a challenging exercise despite feeling fatigued), or the exertion of effort beyond one's preferred or anticipated "comfort zone" (Baumeister et al., 1998; Duckworth et al., 2013; Englert, 2016).

To define and explain self-control, Baumeister and colleagues (1998a; 1998b; 2000) theorized that self-control is a limited resource. According to the self-control strength model (Muraven & Baumeister, 2000), following activation or exertion, self-control becomes temporarily fatigued or depleted, resulting in a state of "ego depletion" (Baumeister et al., 1998). In a state of ego depletion, people who perform tasks requiring self-control are more likely to experience detrimental effects on performance of tasks requiring further exertion of self-control (Hagger et al., 2010; Segerstrom, 2015).

According to Muraven and Baumeister (2000), the effects of ego depletion on self-control are comparable to how a fatigued muscle is less capable of lifting larger weights or sustaining a contraction when exercising. However, unlike a muscle, the effects of ego depletion are not limited to a single action or joint movement. Instead, self-control is an undifferentiated resource that is shared across affective, cognitive, and behavioural domains (Baumeister & Vohs, 2003). Accordingly, when an individual is ego depleted, any thought, feeling or action requiring self-control subsequently falters (Hagger et al., 2010a). The adverse effects of ego depletion on task performance have been documented in several fields, including education (de Ridder, et al., 2012), diet (Kahan, et al, 2003; Vohs & Heatherton, 2000), alcohol consumption (Muraven, et al, 2002), smoking cessation (Leeman, et al, 2010), impulse spending (Vohs & Faber, 2007), and physical activity and exercise (Brown et al., 2020; Englert, 2016).

Ego Depletion Research

Most of the evidence on ego deletion effects is based on a research methodology referred to as the sequential task paradigm. In a sequential task paradigm, a self-control exertion task is used to induce a state of ego depletion (Gillebaart, 2018), which is compared to a “normal” or non-depleted state. The sequential task paradigm typically takes two forms: either an AB design or an ABA design. In the AB design, participants perform an ego depletion manipulation (A) followed by a task requiring self-control (B). In the ABA design, participants perform an initial self-control task (A) to establish a performance “baseline”, which is followed by another self-control task (B); after which they perform the initial self-control task a second time (A) and that performance is compared to their score on the first task (A). For sequential task paradigms, typically a non-ego-depleting task or a no task control condition are used as a comparator condition to the ego depleted condition to assess the magnitude of the ego depletion effect on task performance. Sequential task paradigms are quite effective at revealing the negative effects of ego depletion on task performance. In the first meta-analytic review of the ego depletion effect (Hagger et al., 2010a), 83 studies with 198 independent tests that implemented sequential task paradigms to assess ego depletion were analyzed. Hagger et al. (2010) found ego depletion to yield an average effect size of $d = .62$, indicating ego depletion to have a medium to large effect (Cohen, 1993) on task performance.

One illustrative study included in the Hagger et al. (2010) analysis that demonstrates the negative effects of ego depletion on self-control is a study by Baumeister et al. (1998). Baumeister et al. (1998) performed a multi-experiment study examining how ego depletion alters self-control and subsequent performance. In one of their experiments, using an AB dual-task paradigm design, 67 undergraduate students (36 female) participated in a study that examined the effects of an ego-depleting hunger impulse control task on persistence to solve an unsolvable puzzle. Participants were randomized evenly into either a chocolate cookie, radish, or control group. Participants in the chocolate and radish conditions were exposed to both chocolate cookies and radishes and were tasked with consuming several of each of their condition's food. Participants in the control group were not exposed to the radishes or cookies. For this experiment, it was hypothesized that participants in the radish group would be required to exert higher amounts of impulse control (requiring self-control) to avoid any temptations to want to eat the chocolate cookies. After five minutes of exposure to the food, all participants were required to work on a problem-solving task that they were unaware was impossible to solve. Participants were allowed to attempt the task as many times as they wished, and were informed that they could stop whenever they desired. The results showed that participants in the radish group quit significantly faster than the chocolate cookie or control groups, $F(2, 64) = 5.13$. $p < .01$, $d = –2.14$, supporting the notion that ego depletion negatively affected persistence during a difficult task requiring self-control. Overall, Baumeister et al. (1998) demonstrated that the effortful exertion of self-control in one unrelated domain results in significant ego depletion, and worse performance on subsequent task persistence for tasks that require self-control.

Scrutiny of Ego Depletion Effects

Although numerous studies have shown evidence of ego depletion, there have been several criticisms of, re-examination of data, and attempted replications that have called into question the magnitude and consistency of the ego depletion effect. In particular, Carter et al. (2013; 2014; 2015) criticized the Hagger et al. (2010) meta-analysis for not controlling for possible publication bias, and for including studies that have implemented questionable constructs for measuring or manipulating ego depletion. Due to these questions relating to the Hagger et al. (2010) meta-analysis, Carter et al. (2015) hypothesized that the “true” ego depletion effect was much smaller than the medium to large effect size shown in Hagger et al. (2010). To test their hypothesis, Carter et al. chose to remove several questionable studies from the Hagger et al. (2010) experiment list and re-examined the remaining studies using the precision effect test and precision effect estimation with standard error (PET-PEESE) method, which is a statistical method for assessing meta-analyses that conservatively controls for selection or publication bias (Stanley et al., 2013). Results from Carter et al.’s meta-analysis estimated the effect of ego depletion to be non-significant (g = .003; CI 95% [– .14, .15]). Based on their re-analysis, Carter et al. concluded that, once publication bias was controlled for, the ego depletion effect may not exist, and that researchers examining ego-depletion should be cautious when interpreting their results.

Despite Carter et al. (2015) having provided evidence of limitations of Hagger et al.’s (2010) meta-analysis, a follow-up meta-analysis by Dang (2017) questioned the Carter et al.’s meta-analysis for its over-estimation of publication bias and criticized their use of the PET-PEESE method. Dang (2017) noted that the PET-PEESE method cannot reliably account for small-study effects and that it requires a large number of studies in the absence of heterogeneity

(Inzlicht et al., 2015; Stanley et al., 2014). To address these issues, Dang (2017) conducted a stricter meta-analysis from the Hagger et al. (2010) dataset using the trim and fill method instead of the PET-PEESE method. Dang (2017) also included published and unpublished ego-depletion studies that had been published since the original Hagger et al. (2010) meta-analysis, up until February 2016. Lastly, based on observations from the Carter et al. (2015) meta-analysis, Dang (2017) also chose to conduct separate meta-analytic analyses for varying ego-depleting manipulations. Results from Dang's meta-analysis found the ego depletion effect was indeed smaller than that initially identified in Hagger et al. (2010) (g = .24; CI 95% [.16, .32]), but significantly greater than 0, supporting an ego depletion effect. Additionally, Dang (2017) found significant differences of the ego-depletion effect across ego-depleting tasks. Specifically, food temptation tasks (g = .63; CI 95% [.29, .98]); emotional regulation videos (g = .48; CI 95% [.35, .62]); and the Stroop task (g = .44; CI 95% [.18, .69]) had small to medium corrected effect sizes, compared to other tasks like the attention video task (g = .13; CI 95% [– .02, 0.28]) and working memory tasks (g = – .04; CI 95% [– .32, 0.25]), which produced non-significant effects. Thus, based on the meta-analytic results, Dang (2017) concluded that despite the findings from Carter et al. (2015), ego depletion does seem to show a significant small effect on self-control tasks; and that the degree to which ego depletion alters self-control is affected based on the type of ego-depleting task performed.

In a separate critical examination of the ego depletion effect, Hagger et al. (2016) chose to reassess the existence of the ego depletion effect using a multilab preregistered replication study. In their registered replication report, 23 studies with a cumulative sample of N = 2,141 were performed to assess the ego depletion effect using a standardized ego-depletion protocol based on an AB sequential-task paradigm outlined in Sripada et al. (2014). Results from the meta-analysis of the 23 studies found no significant effect for ego depletion on self-control (d = .04; 95% CI [– .07, .15]), indicating that, like the observations from the Carter et al. (2015) study, ego depletion may have no effect at all on subsequent self-control task performance. However, while Hagger et al. (2016) found a null effect for ego depletion, they also commented on possible limitations presented by their meta-analysis; one limitation being that they only assessed ego depletion using one specific AB sequential task paradigm. Indeed, the limitation of only performing a single ego-depleting task was highlighted in the results from the Dang (2017) meta-analysis that certain tasks may not reliably produce an ego depletion effect. Thus, while Hagger et al. (2016) provided evidence against ego depletion, they did not rule out the possible existence of the ego depletion effect.

Ego Depletion and Physical Performance

Although the effects of ego depletion have come under recent scrutiny (Carter et al., 2013; 2014; 2015; Dang, 2017; Hagger et al., 2016; Vohs et al., 2021), one particular domain where ego depletion has demonstrated a consistent negative effect on task performance is in the sport and exercise science domain (Brown et al., 2020; Englert, 2016; Hunte et al., 2021). A recent meta-analysis by Brown and colleagues (2020) reviewed 73 studies with 91 comparisons to examine the effects of cognitive self-control exertion on physical performance. In their analyses, they examined both published and unpublished literature, and included studies with both within- and between-subjects designs to ensure their meta-analyses encapsulated the broad scope of effects of cognitive exertion on subsequent physical performance. Brown et al. (2020) also recognized a common arbitrary divide for analyses of research in the area of mental fatigue, where previous meta-analyses argued that cognitive tasks needed to last ≥ 30 minutes. Thus, in their analyses, Brown et al. (2020) examined the categorical difference of cognitive manipulations that lasted < 30 and ≥ 30 minutes on physical performance. Lastly, as physical performance encompasses a broad range of types of performance, Brown et al. (2020) further subdivided their analyses based on the parameters of the physical task that a study examined; specifically aerobic, isometric resistance, dynamic resistance, maximal anaerobic and motor-based sport performance tasks.

Overall, Brown et al. (2020) found that exerting cognitive effort prior to performing an exercise task has a significant small to medium negative effect on subsequent physical task performance ($g = -.38$). In their sub-analyses, Brown et al. (2020) found that between-subjects designed studies ($g = -.65$) compared to within-subjects designed studies ($g = -.28$) showed stronger effects of cognitive exertion on physical performance ($p < .05$). A similar distinction was noted for published studies ($g = -.42$) compared to unpublished ($g = -.20$) studies ($p < .05$). Interestingly, they found that the magnitude of effect for lasting < 30 vs ≥ 30 minutes, while distinct, did not significantly differ ($p > .05$) for studies lasting < 30 minutes ($g = -.45$) compared to ≥ 30 minutes ($g = -.30$) and there was no correlation between the length of the cognitive manipulation and the effect on physical performance. Lastly, the effects of cognitive exertion on the subdivided categories of physical activity showed that cognitive exertion had significant negative effects on isometric resistance ($g = -.57$), motor skills ($g = -.57$), dynamic resistance ($g = -.51$), and aerobic performance ($g = -.26$); but the effects on maximum effort tasks such as short sprints and 1-repetition maximum (1RM) tasks were not significant (g = .10).

Another recent meta-analysis by Hunte et al. (2021) examined the effects of prior self-control exertion on subsequent physical performance. Hunte et al. (2021) reviewed 44 articles with 50 comparisons examining the effects of <30-minutes of a self-control exertion task on subsequent physical performance. Similar to Brown et al. (2020), Hunte et al. (2021) subdivided their analyses to compare study design and types of physical tasks when examining the effects of self-control exertion on subsequent physical performance. Overall, results from Hunte et al. (2021) showed a medium to large effect of prior self-control exertion on subsequent physical performance ($g = -.55$). Within-, vs. between-subjects designed studies showed similar sizes of effects ($g = -.54$ and $g = -.53$; respectively). Additionally, results showed similar sizes of effects to those found in Brown et al. (2020) when examining isometric physical tasks ($g = -.62$), dynamic physical tasks ($g = -.61$), aerobic tasks ($g = -.36$) and motor skill tasks ($g = -.45$).

To illustrate how the effects of ego depletion on exercise performance can be assessed, it is helpful to review one of the earliest studies conducted in this area by Bray et al. (2008). Using an ABA sequential task paradigm design, Bray et al. (2008) explored how the ego-depleting effects of an incongruent Stroop task (Wallace & Baumeister, 2002) affected participants' performance on an isometric resistance endurance handgrip task. Upon entering in the study, 49 sedentary university students (35 female) each performed an isometric resistance endurance handgrip task at 50% of their maximal voluntary contraction (MVC) until failure. Participants were then randomized and stratified by gender to either the ego depletion (n = 26) or control (n = 23) groups. Participants in the ego depletion group performed 3 minutes and 40 seconds of the incongruent Stroop task, whereas participants in the control group performed 3 minutes and 40 seconds of the congruent Stroop task (sham control). After completing the cognitive task, participants performed a second isometric resistance endurance handgrip task at 50% MVC until failure. Performance results were assessed using residualized change scores to control for the variation in participant performance during the pre-test isometric resistance endurance handgrip task. Results from Bray et al. (2008) found a significant difference in time to failure (TTF) during the isometric resistance endurance handgrip task where the ego depletion group performed significantly worse than the control group, $F(1, 47) = 6.92$, $p < .01$, $\eta_p^2 = .13$.

A similar example of the negative effects of ego depletion on exercise performance can be seen in a study by Dallaway et al. (in review[a]). In their study, the researchers tested how ego depletion affects exercise performance for dynamic and isometric calisthenic exercises (push-ups, wall sits, and planks). Dallaway et al. recruited 29 healthy undergraduate participants (12 female) to engage in a series of physical and cognitive tasks. Participants were instructed to perform a set of calisthenic exercises until exhaustion (pre-test). After completing the first set of calisthenic exercises, using an ABA sequential task paradigm, participants performed 20-minutes of a cognitively demanding 2-back test (Braver et al., 1997) followed by a second set of the calisthenic exercises until exhaustion (post-test). No control group was included in their study. When comparing pre-, to post-test outcome performance for each exercise task, there was a significant decrease in exercise performance for participants' number of push-ups $M_{pre\text{-}test} = 130.62$ s $> M_{post\text{-}test} = 106.46$ s), $p < .001$, $\eta_p^2 = .434$); and plank time to failure, ($M_{\text{pre-test}} = 130.62$ s $> M_{\text{post-test}} = 106.46$ s), $p < .001$, $\eta_p^2 = .434$); and a negative change for wall sit TTF that approached significance $M_{pre\text{-}test} = 130.62$ s $> M_{post\text{-}test} = 106.46$ s), $p < .001$, $\eta_p^2 = .434$). Overall, Dallaway et al. demonstrated that ego depletion has a significant negative effect on exercise performance during dynamic and isometric resistance exercises.

Ego Depletion and Ratings of Perceived Exertion

In conjunction with the adverse effects it has on exercise performance, ego depletion has also been shown to have a significant negative effect on how people perceive their levels of exertion while performing an exercise task (Langvee & Bray, 2017; Wagstaff, 2014; Zering et al., 2017). When exercise is performed at a continually maintained workload (e.g., cycling at

60% VO_{2max}; sustained handgrip isometric contraction at 50% MVC) until failure, the degree of perceived exertion experienced increases as the duration of performance progresses (Garcin et al., 1998; Lea et al., 2022). However, when ego depleted, the perceived exertion over time increases at an accelerated rate (Langvee & Bray, 2017; Wagstaff, 2014; Zering et al., 2017). Essentially, people who are ego depleted perceive exercise tasks to be more effortful, or require greater exertion, throughout the task compared to those who are in a non-ego depleted state.

Wagstaff (2014) demonstrated the negative effects of ego depletion on exercise performance and ratings of perceived exertion (RPE). Using a within-subjects, counterbalanced, AB sequential task paradigm design, Wagstaff (2014) examined the effects of ego depletion (specifically emotion suppression), on a 10km cycling time trial in a sample of 20 competitive undergraduate athletes (10 female). Each participant completed tasks involving three conditions, including an emotion suppression, non-suppression and control condition. During the emotion suppression and non-suppression conditions, participants were required to perform a short modified incongruent Stroop task (70 words; Wallace & Baumeister, 2002), followed by watching a video excerpt that was previously shown to elicit strong feelings of disgust (De Jong et al., 2002). When participating in the emotion suppression condition, participants were asked to not express any emotion or behaviour that would indicate how they felt from watching the video; whereas when participating in the non-suppression condition, participants were not given any instructions to suppress emotion. During the control condition, participants were not exposed to the incongruent Stroop task or the video excerpt. Following the incongruent Stroop task and video excerpt, participants performed a 10km cycling time trial at a fixed gear. During the time trial, power output was assessed every two-minutes, and perceived exertion was assessed every two kilometers using the Borg (1983) 15-point scale. When comparing the emotion suppression condition to the non-suppression and control conditions, there was a significant negative effect of ego depletion on cycling time $p = .02$, $d = .41$; on mean power output, $p < .01$, $d = 1.44$; and on subjective ratings of perceived exertion (observed as higher ratings of perceived exertion at most time points throughout the cycling task), $p < .01$, $d = .72$. Thus, Wagstaff (2014) demonstrated how ego depletion not only affects performance on a task, but also identifies that people experience an increase in perceived effort throughout their task due to the negative effects of ego depletion.

Synopsis of Evidence on Ego Depletion effects on Physical Performance and RPE

The literature to date provides consistent evidence that ego depletion significantly negatively impacts exercise performance and perceptions of exertions during exercise. Apart from maximal anaerobic tasks, performance during physical exertion tasks is significantly diminished when in a state of ego depletion (Brown et al., 2020; Hunte et al., 2021). Not only does ego depletion alter the performance of the task, but it also alters perceived task difficulty and required effort to perform the task (Langvee et al., 2017; Wagstaff, 2014; Zering et al., 2017). Thus, ego depletion is an all-around negative phenomenon that should be avoided if an individual wishes to perform their best in an exercise task and perceive their task as less effortful. However, given the dynamic and often uncontrollable nature of physical performance environments (e.g., competitive sport), ego-depletion may be an unavoidable state for many participants. Given the theoretical premise that self-control is like a muscle, it is possible that ego-depletion may be used strategically to build self-control stamina. Indeed, evidence suggests that it is possible to use ego-depleting tasks to practice self-control and elicit positive benefits on task performance. In other words, rather than diminishing self-control over and over again, literature has shown that performing ego depleting tasks over a prolonged period can, in fact, positively improve an individual's ability to exert self-control (Allom et al., 2016). Currently, two alternative exercise training techniques use ego-depleting tasks to train self-control capacity with the goal of improving exercise performance – a generic form referred to as: self-control training and a more specific form involving cognitive tasks: brain endurance training.

Self-control Training

Self-control training (SCT) aims to improve or strengthen self-control through systematic practice or training involving repetitive exertion of an individual's self-control (Berkman et al., 2012). SCT was derived from the same principle which underlies most training research – Selye's general adaptation syndrome (Selye, 1950). Selye's general adaptation syndrome states that there are three phases of a stress response: alarm reaction, resistance, and exhaustion phase. The alarm reaction phase refers to the initial symptoms that the body experiences after being placed under stress; typically, this is when the body exhibits fight or flight responses. The resistance phase refers to the period after the initial stress response in which the stress response does not disappear, and so the body adapts to compensate against the stress. Lastly, the exhaustion phase is the "breaking point" in which the body is no longer capable of resisting or adapting to a stressor, resulting in a reduction in strength against the stressor. Within most training experiences, it is important to avoid entering the exhaustion phase. Comparing self-control and ego depletion to Selye's general adaption syndrome, the initial exposure to an ego-depleting task elicits the alarm reaction phase's negative stress response. In the alarm reaction phase, due to the stress of ego depletion, the body experiences detrimental sensations of fatigue resulting in worse performance on self-control tasks. However, when self-control is repeatedly stressed over time by the application of ego-depleting tasks, self-control resources adapt and responds to the repeated stressor similar to the resistance phase. In the resistance phase, the repeated and controlled exposure to the ego-depleting tasks allows the body to adapt to the stress, resulting in improved self-control. Thus, the adaptation to stressors that cause ego depletion explains how it is possible to improve self-control through systematically applied training techniques.

Improving self-control by applying stress to develop self-control resources has been investigated across several domains (Beames et al., 2017). A meta-analysis by Friese et al. (2017) reviewed 28 articles with 33 studies (23 published, 10 unpublished) to examine the effects of SCT on subsequent self-control task performance. In their analyses, Friese et al. (2017) examined how treatment-, study-, and outcome-level moderators influenced the effect of SCT on task performance. The type of SCT training task (i.e., inhibitory control, handgrip, non-dominant hand, posture regulation, or diet regulation tasks) was assessed as a treatment-level moderator. Study-level moderators included the length of training, publication status, research group (binary coding assessing if one of the researchers in the study initially contributed to the self-control strength model; i.e., Baumiester, DeWall, Gailliot, Muraven, Schmeichel, and Vohs), control group quality (inactive vs active), and gender ratio. Outcome level moderators included type of outcome, lab vs real world, stamina vs strength (performing or not performing an ego-depleting task before the assessment task), maximal vs realized potential, and any follow-up assessments.

Overall, Friese et al. (2017) found the effects of SCT on subsequent self-control task performance had a significant small to medium positive effect on subsequent self-control task performance (g = .30). In their sub-analyses, when examining treatment-level moderators, Friese et al. (2017) found no significant difference between the type of training task on subsequent self-control task performance (*p* = .42). When examining study level moderators, Friese et al. (2017) found only research group to have a significant difference of effect for SCT on subsequent self-control task performance, with research groups that included one of the founders of the self-control strength model (*g* = .51) reporting significantly higher effects compared to other studies (*g* = .22; *p* = .028). No significant differences for the moderating effects of length of training time (*p* = .682), publication status (*p* = .098), control group quality (*p* = .099), and gender ratio (*p* = .064) were found for the effect of SCT on subsequent self-control task performance. Nonetheless, when examining length of training time, it was noted by the authors that there were few studies examining SCT at greater than 2 weeks, which may have precluded a meaningful test of the length of training time as a moderator. When examining outcome level moderators, only the difference of stamina compared to strength tasks was observed to be significantly different, with SCT having a significantly larger effect on stamina tasks (assessment tasks that were preceded by an ego-depleting task; *g* = .60) compared to strength tasks (*g* = .21; *p* = .01). No significant effects were observed for type of outcome, lab vs real world, maximal vs realized potential, and any follow-up assessments (*p*'s > .05). Overall, Friese et al. (2017) demonstrate the effectiveness of SCT on subsequent task performance, highlighting the potential SCT has for improving self-control.

A key characteristic utilized in SCT studies is how they repetitively expose participants to tasks that require self-control but that are unrelated to the primary measurement task. For example, in the first study to examine the potential effects of SCT, Muraven et al. (1999) explored how performing repetitive ego-depleting tasks over the course of two weeks affected performance on an isometric resistance endurance handgrip TTF task. Muraven et al. (1999) recruited 69 undergraduate students (27 female) to participate in their two-session study. During the first session, using an ABA sequential task paradigm, each participant performed an isometric resistance endurance handgrip TTF task using a spring-loaded handgrip device, before and after a thought suppression task. The thought suppression task required participants to "not think about a white bear" (Wegner et al., 1987) for five minutes. After each participant performed both isometric resistance endurance handgrip TTF tasks and the thought suppression task, participants were divided into four different training groups: posture, mood regulation, food diary 1, food diary 2 and a no effort control group. For the following two weeks, the posture group was tasked with always maintaining good posture; the mood regulation group was tasked with constantly try to improve their mode by maintaining a positive mood whenever they could; the food diary groups were tasked with writing an extensive diary about their food intake; and the no-effort control group was given no instructions. The four experimental conditions were required to keep a record of their efforts across the two-week period to ensure compliance. After the two weeks, participants returned for their second session, where they repeated the procedures performed during the first session. Results showed a significant three-way interaction between Group X Pre-Post thought suppression X Session, $F(4,64) = 2.69$, $p < .05$, $d = .72$. Post-hoc analyses showed participants who performed SCT for two weeks had a significantly greater positive change in handgrip TTF than the control group, $F(1,64) = 5.57$, $p < .025$. This study was the first to demonstrate the feasibility of SCT and how repetitively performing unrelated self-control exertion tasks can improve self-control performance.

Following the seminal research of Muraven et al. (1999), several other studies have found similar positive effects from SCT using unrelated ego-depleting tasks to improve self-control on focal tasks. Examples of SCT training techniques included everyday tasks like avoiding slang or swearing while speaking in conversation, using a non-dominant hand to perform activities of daily living, or performing exercises such as endurance handgrip tasks (Beames et al., 2017).

Although many studies examining SCT have been designed to provide evidence in-principle, improving self-control through SCT has been shown to have many practical benefits. For example, performing SCT repetitively over time, is associated with improved academic performance (Job et al., 2015), reduced anger and aggression (Denson et al., 2011), improved healthy eating behaviours (Davisson, 2013), lower incidence of smoking relapses (Muraven, 2010), reduced impulse spending (Sultan et al., 2012); and, of particular importance to this study, improved endurance performance of an exercise task (Bray et al., 2015).

Self-control Training and Exercise

Although the muscle analogy put forth by Muraven and Baumeister (2000) provided a compelling rationale for investigating the effects of SCT on physical exercise performance, a study by Bray and colleagues (2015) was the first to examine if SCT could be used as a potential training technique in the sport and exercise performance domain. Drawing parallels with exercise training principles from cross-training, Bray et al. (2015) hypothesized that a SCT protocol using an exercise task that did not require cardiovascular endurance could be applied to improve cardiovascular endurance performance if both the training and performance tasks required self-control to perform. To test their hypothesis, they recruited and randomized 41 undergraduate participants (26 female) to either a SCT group ($n = 20$) or a no-training control group ($n = 21$).

To measure the effects of SCT on cardiovascular performance, Bray et al. (2015) had each participant perform a self-control sequential-task paradigm (AB design) using an ego-depleting incongruent Stroop task (Wallace & Baumeister, 2002) followed by a cycling graded exercise task (GXT: cycling until failure while the workload increases steadily over time) at pre-, and post-training. During training, participants in the SCT group were tasked with performing endurance handgrip squeezes until failure using a spring-loaded handgrip device, twice daily, five days a week, for two weeks. In contrast, the no-training control group was instructed to go about their daily lives as normal, but not to change their current physical activity levels.

During pre-, and post-training testing sessions, the researchers measured participants' TTF on the cycling GXT. Examination of the cycling GXT TTF results revealed a significant ($p < .05$) time X group interaction with a very large effect size (Cohen's $d = 1.67$). The SCT group improved their performance ($TTF_{post} – TTF_{pre}$) by +15.6 seconds (378.65 [*SD* = 47.09] compared to 363.05 [*SD* = 48.03]) from the pre- to post-testing session. In comparison, the control group saw a reduction in their performance by -12.15 seconds (342.51 [*SD* = 47.98] compared to 354.66 [*SD* = 47.84]) from pre- to post-testing.

Despite the significant effects of SCT on exercise performance observed by Bray et al. (2015), further exploration of SCT in the exercise science area has yet to materialize. Given the novelty of SCT as a potential training modality for exercise performance and the variability in SCT effects seen in the literature (Beames et al., 2017; Friese et al., 2017) future research is warranted.

Brain Endurance Training

Brain Endurance Training with Exercise

SCT was developed based on the premise that self-control can be trained using tasks that require self-control and can improve similar or dissimilar tasks that also require self-control. In contrast, brain endurance training (BET) was designed to improve exercise performance by mitigating the negative effects of mental fatigue. Staiano et al. (2015) proposed that an endurance athlete's perception of effort was the greatest limiting factor to their performance (Marcora et al., 2008; Marcora & Staiano, 2010). Accordingly, Staiano et al. (2015) hypothesized that improving endurance performance should necessarily develop the brain's capacity to overcome limitations related to perceptions of effort. Acknowledging that the brain is plastic and can adapt to various stressors and stimuli (Kolb & Whishaw, 1998), Staiano and colleagues (2015) proposed that it would be possible to use acute mentally fatiguing tasks as training stimuli to improve brain capacity development. They theorized that experiencing repetitive acute mental fatigue during exercise could improve functioning in areas of the brain responsible for the perception of effort (prefrontal cortex). By altering areas of the brain responsible for the perception of effort, BET would improve resiliency against feelings of effortful exertion in future physical tasks, thereby improving future performance (Staiano et al., 2015).

To test BET, Staiano et al. (2015) randomized 35 male volunteers into a 12-week training study. Participants performed baseline testing assessing TTF for a cycling task at 75% of their VO_{2max}. After baseline, participants were randomized into either a BET or control group. All participants trained for 60 minutes on a cycle ergometer at 65% VO_{2max}, three times a week for 12 weeks. Participants in the BET group also performed the cognitive AX – Continuous Performance Test (AX-CPT) task throughout each cycling training task. After 12 weeks of training, participants returned to perform another TTF cycling task at 75% of their VO_{2max}. When comparing pre-, to post-training, Staiano et al. (2015) found a significant group X time interaction, with participants in the BET group improving their performance by approximately 125%, compared to the control group, which improved by approximately 40% ($p < .001$). Furthermore, when comparing RPE between conditions, Staiano et al. (2015) found that the BET group had a significantly higher tolerance to perceived exertion over time ($p < .001$), reporting lower RPE scores and reduced RPE scores across the trial duration at post-training. Staiano et al. (2015) provided evidence that it was possible to use acute mental fatigue combined with exercise as a training strategy to significantly improve performance and perception of exertion for an exercise task.

In another study investigating the effects of BET on exercise performance and RPE, Dallaway et al. (2021) demonstrated that BET can alter resistance exercise performance and provided evidence to suggest that BET does indeed alter the neurophysiology of the brain (specifically in the prefrontal cortex). Using a mixed-design randomized control trial, 36 healthy undergraduate participants (15 female) were randomized to either a BET or control group. At baseline, participants performed 300, 1-second maximal force dynamic rhythmic muscular endurance handgrip squeezes on a handgrip dynamometer. Over eight weeks, all participants performed 24 training sessions. Each participant performed dynamic rhythmic muscular endurance handgrip squeezes on a handgrip dynamometer at 30% of their MVC until reaching a pre-determined cumulative force production target for each training session. In addition to the handgrip exercise, participants in the BET group also performed several cognitively-demanding tasks such as the 2-back task (Braver et al., 1997) and the incongruent Stroop task (Wallace & Baumeister, 2002), while performing the handgrip training task. After completing the 8 weeks of training, participants performed another 300, 1-second maximal force dynamic rhythmic muscular endurance handgrip squeezes. Results showed participants in the BET group produced significantly greater amounts of force compared to their own pre-training scores as well as superior performance compared to the control group ($p < .001$), with average maximal force increasing from 421N (SD = 99N) at pre-training to 485N (SD = 116N) at post-training. In addition, near-infrared spectroscopy (fNIRS) recorded during the testing sessions showed a significant reduction in hemodynamics in the brain's prefrontal cortex in the BET group at post-training compared to pre-training as well as compared to the control group. With these findings, Dallaway et al. (2021) provided evidence to both support BET as an effective training technique for improving exercise performance, as well as evidence to support the theory of Staiano et al. (2015) that brain plasticity within the prefrontal cortex is an underlying mechanism by which BET improves endurance performance.

Brain Endurance Training without Exercise

To this point in time, several studies have provided evidence that, with as little as four weeks of training (Staiano et al., 2019), BET has substantial effects on endurance during cardiovascular fitness tasks (Staiano et al., 2015), dynamic resistance exercise tasks (Dallaway et al., 2021; Dallaway et al., in review[a]), and sport-specific performance tasks (Staiano et al., 2019). However, despite the significant implications of BET on exercise performance, evidence suggests that BET may need to be practiced in combination with a physically-demanding task to produce positive training effects and may not be an effective training technique on its own. In a multi-study by Dallaway et al. (in review[b]), BET was found to be ineffective for improving either handgrip force production or cycling performance using only cognitively demanding tasks (BET-only) as a training stimulus.

In Dallaway et al., under review; Study 1, 22 undergraduate participants (15 female) performed 300 1-second maximal force dynamic rhythmic muscular endurance handgrip squeezes on a handgrip dynamometer at a baseline testing session. Participants were then randomly divided into a BET-only group or a control group. Participants in the BET-only group performed 20 training sessions over the seven weeks. Each training session involved the participant performing a 20-minute cognitively demanding BET task (2-back or incongruent Stroop tasks; Braver et al., 1997; Wallace & Baumeister, 2002) without any physical exercise. Participants in the control group performed no training. After the seven weeks, participants returned and performed the same 300 one-second handgrip task as they performed at baseline. Analyses of force production on the handgrip task showed no significant group (BET-only, control) X time (pre-, post-training) or interaction effects ($p = 1.0$).

In Study 2, 22 undergraduate participants (12 female) performed a cycling GXT to failure on a cycle ergometer at baseline. Participants were then randomized into either a BET-only or control group. Both groups performed nine training sessions over the two weeks. Participants in the BET-only group performed several challenging cognitive tasks including: the incongruent Stroop task (Wallace & Baumeister, 2002), the stop-signal task (Schachar et al., 2000), and the typing inhibition task (Muraven et al., 2006). Participants in the control group performed several "sham" cognitive tasks (congruent Stroop task, sham stop-signal task, and sham typing inhibition task) requiring minimal cognitive effort. After the two weeks of training, participants returned to perform a second cycling GXT to failure. Results of this study also showed no differences in performance between the BET-only and control group on physical performance $p = .52$. Together, results of these studies show BET may be ineffective at improving exercise performance when performed without a coupled physical task. However, research has yet to explore how much of a coupled physical training task is needed to elicit changes in performance and whether a non-related exercise task (like SCT) can be coupled with BET to significantly improve performance.

Study Purpose

The overarching purpose of this study was to examine the effects of SCT and BET on endurance task TTF in a cognitively fatigued state. This study followed a similar protocol to that implemented by Bray et al. (2015); however, due to COVID-19 restrictions, the study protocol was performed remotely, using videoconference. To accommodate a remote setting, a high plank endurance task was used in place of a cycling GXT on a cycle ergometer. We examined effects of two and four weeks of SCT and SCT+BET (compared to each other as well as to a no training (control) group) on endurance performance of a high plank exercise. Following from research examining RPE while performing exercise in a mentally fatigued or ego-depleted state, this study also examined participants' RPE throughout their high plank performances following two and four weeks of training to observe if SCT or SCT+ BET affected patterns of RPE. Due to timing constraints and resource considerations and considering the lack of effects of BET-only on exercise performance (Dallaway et al., in review[b]), this study used an incomplete 2 X 2 factorial design that did not include a BET-only group.

Hypotheses

Hypothesis 1: Based on the self-control strength model and previous research by Bray et al. (2015), it was hypothesized that participants who engaged in SCT would show significant improvements in their high plank TTF following two and four weeks of training compared to the control group.

Hypothesis 2: As BET has been observed to significantly alter performance after 4-weeks of training (Staiano et al., 2019), and SCT has found to improve exercise performance after 2-weeks of training (Bray et al., 2015), it was hypothesized that participants who engaged in two and four weeks of SCT+BET would see significant improvements in their post-training high plank TTF compared to the control group.

Hypothesis 3: This is the first study to examine the combined effects of SCT and BET on exercise performance. Given SCT and BET are theorized to develop exercise performance capacity through separate pathways, it was hypothesized that in the SCT+BET would result in greater performance improvements than SCT alone after 2 weeks and 4 weeks of training.

Hypothesis 4: Based on previous ego depletion research by Wagstaff (2014) and Zering et al. (2017) showing that ego-depletion negatively effects RPE during subsequent exercise, it was hypothesized that participants in the SCT group would have significant reductions in RPE during the high plank TTF task compared to the control group.

Hypothesis 5: Based on previous research by Staiano et al. (2015) showing BET decreases RPE during exercise, it was hypothesized that participants in the SCT+BET group would have significant reductions in RPE during the high plank TTF task compared to the control group.

Methods

Participants and Design

The sample ($N = 39$; $M_{age} = 21.0$, $SD = 3.06$) was comprised of participants who self-identified as "recreationally active" ($n = 24$ female, 15 male), engaging in ≥ 60min of moderate to vigorous physical activity (MVPA) per week at the time of recruitment and having normal vision (i.e., not colour-blindness). Participants were required to own a smartphone or tablet device that could operate iOS 10+ in order to access the BET application. Prior to the start of the study, all participants were screened for medical contra-indicators using the PAR-Q (Thomas et al., 1992).

The design was a 3 (experimental condition) X 3 (time) mixed factorial. The sample was stratified by sex and randomized to one of three groups: SCT ($n_{SCT} = 15$ [8 female]), SCT+BET ($n_{SCT+BET} = 13$ [8 female]), and no-treatment control ($n_{control} = 11$ [7 female]). The study protocol was reviewed and approved by the McMaster research ethics board and participants provided informed consent prior to the start of the study. Participants were compensated for their time up to $100.

Sample size analysis

A sample size/power analysis was computed with WebPower analysis's sample size estimator in *R*. Due to time constraints, resource limitations, and lack of meta-analytic evidence for the effects of SCT or BET on exercise performance, the sample size calculation for this study was based on the one existing SCT study focusing on the effects of SCT on endurance exercise performance (Bray et al., 2015). Using $\alpha = 0.05$ and $\beta = 0.80$ and the effect size of Cohen's $d = 1.67$ from Bray et al. (2015), a sample size estimate of 31 participants was calculated to be sufficient for analysis for a 3 (group) X 3 (time) mixed factorial design.

Randomization Procedure

Participant randomization tables were created prior to study launch using the Microsoft Excel™ 'randbetween()' function. To randomize male participants into the three different groups, the 'randbetween()' function generated 24 random numeric values between 1-3 (with each number being generated eight times). This randomization process was repeated a second time to create a randomized table for females. Thus, two tables of 24 numeric values (48 total pre-randomized values) between 1-3 were computed. When a participant started session two (pre-training session), their participant identification (ID) was placed on their respective sex's randomization table (based on their identified sex) in the next available row. Participants were assigned to a specific group based on the numeric value their ID was written beside; with '1' indicating SCT+BET group, '2' indicating SCT group, and '3' indicating Control group.

Primary Outcome Measures

High Plank Endurance Task Performance

Performance on a high plank endurance task was the primary dependent variable. The high plank used in the current study was adapted from the task used by Stocker et al. (2018). A visual and text description of the high plank task is presented in Figure 1. A plank endurance task was chosen for this study based on its broad accessibility, ease of execution, adaptability for at-home use (Yates et al., 2018), and based on prior research showing performance on isometric physical endurance tasks (such as a plank task) require self-control and are susceptible to ego-depletion effects (Dallaway et al., in review).

Given the high plank endurance task was novel to most participants, a familiarization/ training session was conducted prior to the study to acquaint them with the task. Participants watched a video providing a model's demonstration of the task along with verbal instructions to:

"keep the palms of the hand placed flat on the ground, fingers facing forward, hands shoulder width apart, elbows fully extended, and maintain a neutral spine throughout the task". Following the visual demonstration and instructions, participants were asked to provide a brief (approximately 5 second) demonstration of the high plank task to demonstrate their capacity to successfully perform the task. If participants demonstrated effectively how to perform a high plank, no additional instructions were given. Otherwise, if errors in the high plank were observed, cues including, "please lower/raise your hips" or, "please try to push your palms into the ground" were used to instruct participants of any hip or shoulder deviations respectively. Once participants demonstrated proper high plank form, they were given a brief moment to rest before performing a familiarization high plank test trial.

Performance on the high plank task for all testing sessions was operationalized as time to failure (TTF) represented by the duration (in seconds) from the point in time when participants assumed the high plank position until they willingly chose to end the task by placing their knee(s) on the ground or until they could no longer maintain the plank position for five seconds after being verbally instructed to correct the position by the experimenter. Participants were instructed to maintain the position of the high plank for as long as possible and were informed of the conditions (e.g., not being able to correct their form after receiving instructions to do so) that would signal termination of the task prior to starting the task. While performing the plank task, participants were observed continuously by the experimenter via videoconference and given corrective feedback if they did not maintain correct form.

Figure 1. Visualization of a high plank. A high plank consists of four contact points on the ground (both hands and feet), while keeping the palms of the hand placed flat on the ground, fingers facing forward, hands shoulder width apart, elbows fully extended. A high plank also requires a neutral spine consisting of the legs, thighs, waist, abdomen, back and shoulders forming a straight line. When engaging in a high plank, muscle activation should be felt primarily in the abdomen, gluteals, and shoulders.

Rating of Perceived Exertion (RPE)

Borg's Category Ratio-10 (CR-10) scale (Borg, 1998) was used to assess participants' rating of perceived exertion (RPE). The RPE scale prompts respondents to rate exertion ranging from 0 (no exertion at all) to 10 (maximal exertion). Participants were provided with a digital copy of the scale and were required to have the digital or a printed physical copy of the scale visible, for reference, during their endurance exercise task. RPE was reported, verbally by participants, at 20 second intervals throughout the endurance performance task.

Experimental Manipulations

Incongruent Stroop Task

Following procedures described in Bray et al. (2015) and Brown and Bray (2017), a version of the incongruent Stroop task (Stroop, 1935; Wallace & Baumeister, 2002) was implemented to ego-deplete all participants prior to performing the high plank endurance task. The incongruent Stroop task used in the current study displayed a string of words of the names of colours (e.g., red, blue, yellow, green) that required participants to say aloud the colour of the font of a word as it appeared on their computer monitor screen while ignoring the mis-matched printed colour word (e.g., if the word "red" was printed in "green" ink, the participant would say aloud "green"). Words were presented on the monitor in rapid succession. Each word was visible on the screen for 800ms followed by a 100ms blank screen. Each trial block of the incongruent Stroop task consisted of 135 printed words appearing on the screen over a span of 120 seconds, followed by a 30 second pause for participants to report their mental fatigue. For each session, participants would complete five incongruent Stroop task sections back-to-back for a total of 10-minutes. Adopting these procedures allowed for a re-examination of the SCT effects in the original Bray et al. (2015) study and allowed for examination of the study hypotheses from a common manipulated state of self-control fatigue/ego-depletion, which is standard protocol for research investigating self-control training effects (Friese et al., 2017).

Apparati

Microsoft Teams

Microsoft Teams was used as the digital platform for online video session meetings with participants. A total of four videoconference sessions (familiarization, pre-, mid-, post-training) were conducted with each participant. Participants had their cameras turned on throughout the duration of the video call to interact with the experimenter and be in view of the experimenter (side view) during the high plank tasks.

LimeSurvey

LimeSurvey was used as a secure online survey software platform to collect participants' weekly training logs and in-session surveys.

Training Logs. Participants completed daily digital logs corresponding to each of their 18 training days. For each training day, participants reported: training week (i.e., 1-4), day of the week, time of day, ratings of mental fatigue pre- and post-training session, and whether they performed the handgrip SCT on that training day. Mental fatigue was reported using a visual analogue scale (see description below) before and after the training day's 10-minute cognitive task (either a Soma Neuro Performance Technology [NPT] cognitive task or viewing a documentary video). A copy of a sample training log is presented in Appendix A.

In-Session Surveys. During each study session, participants completed an in-session survey. These surveys included demographic questionnaires (familiarization session only), the International physical activity questionnaire (IPAQ; Craig et al., 2003), and one (familiarization session) or six (pre-, mid-, post-training) MF-VAS questions (one performed prior to the incongruent Stroop task, and additional corresponding to each section during the incongruent Stroop task). The in-session survey was completed prior to beginning the high plank endurance task.

Soma Neuro Performance Technology (NPT)

Soma Neuro Performance Technology (NPT) (SSwitch, Switzerland, n.d.) is a cognitive performance training platform specifically designed to manipulate cognitive loads in athletes' training protocols (Soma NPT, 2022). Soma NPT allows coaches (or researchers) to create customizable cognitive training plans for individual athletes or whole teams. A large array of cognitively-demanding tasks (e.g., incongruent Stroop task) and sham tasks (e.g., congruent Stroop task) are accessible in the app to design training programs that athletes can perform at varying difficulties (e.g., varying stimuli latency periods) and for varying training durations (i.e., 1, 3, 5, 10, 20, 30 minutes). Athletes interact with the Soma NPT platform using tactile or verbal responses for each cognitive task. Soma NPT also provides coaches with performance feedback reports on variables measuring individual training sessions and long-term adaptations (e.g., accuracy, reaction time, variation in responses, improvements in performance). Participants in the SCT+BET group downloaded the app to their phone or tablet prior to beginning training, and were provided a tutorial on how to properly use the app.

Training Manipulations

Self-Control Training (SCT)

Participants in the SCT and SCT+BET groups were provided a spring-loaded handgrip device (NIYIKOW adjustable resistance [10-60kg] hand grip strength trainer; see Figure 2) by the researchers for use at home. Handgrip resistance tension was set to a participant-selected difficulty. An effective training difficulty was described to participants as “a difficulty that feels challenging and would require constant force to hold, but not so difficult that it could not be held for at least 30 seconds.” Participants were prescribed a training regimen consisting of squeezing and holding the handles firmly together for as long as possible in their dominant hand, twice daily (with at least 30 sec rest in between handgrip squeezes). Participants were asked to set up the tension on the handgrip device and demonstrate how to effectively use the device at the end of the pre-training session (session 2) with the researcher. Eighteen sessions were prescribed, such that participants performed the SCT (handgrip) task on all weekdays over the course of four weeks, except for the two weekdays when they engaged in the mid- and post-training testing sessions (i.e., week 1 = 5 sessions, week 2 = 4 sessions, week 3 = 5 sessions, week 4 = 4 sessions).

Figure 2. NIYIKOW adjustable resistance [10-60kg] hand grip strength trainer used for SCT and SCT+BET training.

Self-control Training Plus Brain Endurance Training

Participants in the SCT+BET group were prescribed the SCT training protocol described above as well as BET. Specifically, in addition to SCT (i.e., prior to performing the two endurance handgrip squeezes) for each training session, they completed a 10-minute BET session using the Soma NPT app (SSwitch, Switzerland). Cognitive tasks for BET were selected based on the available training durations programmed in the Soma NPT app and based on findings from Brown & Bray (2017) which showed that at least 6-minutes was a necessary duration to perform cognitive tasks that result in mental fatigue performance decrements. Participants performed three cognitive tasks from the Soma NPT task battery. The three tasks were: the 2-back task (Braver et al., 1997), the time load dual back task (TLDB; Jacquet et al., 2021), and the task switching task (Alves et al., 2013). To limit practice/learning effects, the sequence of task presentation was varied such that the 2-back task was used for training sessions 1, 6, 8, 10, 15, 17; the TLDB task for sessions 2, 4, 9, 11, 13, 18; and the task switching task for sessions 3, 5, 7, 12, 14, 16. To accommodate the testing sessions during weeks 2 and 4, training sessions 1-5 were performed during week 1; 6-9 during week 2; 10-14 during week 3; and 15-18 during week 4. To further accommodate learning/habituation for each cognitive task, difficulty/intensity was manipulated such that it increased over time by decreasing the latency period between target stimuli using Soma NPT's built-in percent intensity scale. Specifically, intensity increased 10% weekly, such that during week 1, task intensity was 60% and increased to 70%, 80%, and 90% during weeks 2-4. After completing each session, participants were given feedback on accuracy and variation of their responses during that session.

2-back Task. The 2-back task is a memory updating task that imposes high mental workload (Braver et al., 1997; Kirchner, 1958). For this task, participants observe a series of letters presented in random order in the centre of the screen of their smartphone or tablet for a 500 ms interval, followed by a pause with a latency period for 2500 ms (week 1), 2000 ms (week 2), 1500 ms (week 3) or 1250 ms (week 4). During stimuli presentation or the latency period, participants are instructed to tap the bottom left side of the screen if the letter displayed matched the letter presented two letters earlier or tap the bottom right side of the screen if it did not.

Time Load Dual Back (TLDB). The time load dual back (TLDB) task combines an N-back working memory updating task (similar to the 2-back test) with an interfering odd/even decision task (Jacquet et al., 2021). For this task, participants observed a series of numbers (between 1-9) and alphabetical letters in the center of their device screen. Letters and numbers would appear on the screen in a sequential manner at a 1:1 ratio (e.g., F, 5, Q, 2, etc…). When presented with an alphabetical letter, participants were tasked with indicating if the letter matched the previous alphabetical letter presented (1-back test) by tapping on the bottom left of their screen (if it matched) or by doing nothing (if it did not match). When presented with a number, participants were tasked with indicating if it was an odd or an even number. by tapping on a 1 or a 2 located at the bottom ride side of their screen for an odd or even number, respectively. Participants could respond while the stimulus was presented or during the latency period before the next stimulus. Stimuli (letters or numbers) were presented on the smartphone or tablet screen for a 500 ms interval followed by a pause with a latency period of 2500 ms (week 1), 2000 ms (week 2), 1500 ms (week 3) or 1250 ms (week 4).

Task Switching. The task switching task combines a modified task switching test (Alves et al., 2013) with a modified Simon task (Simon, 1990). For this task, participants observed a series numbers ranging from 1-10 presented sequentially on the left or right side of their device screen. Participants were required to indicate if the number displayed on their screen was presented in the colour white and ranged between 1-5 or 6-10, or if the number was presented in the colour red and was an even or odd number. For numbers between 1-5 presented in white, or for odd numbers presented in red, participants were required to respond by tapping the bottom left side of their screen. For numbers between 6-10 in white, or even numbers in red, participants were required to respond by tapping the bottom right side of their screen. Participants could respond to each stimulus while the stimulus was presented or during the latency period before the next stimulus. This task also implemented the modified Simon task (Simon, 1990), whereby the numbers would appear randomly on the left or right side of the screen while also being written in varying font sizes. For this task, individual stimuli would present themselves on screen for a 500 ms interval followed by a pause with a latency period that randomly ranged from 800-1000 ms (week 1), 600-800 ms (week 2), 350-600 ms (week 3) and 200-300 ms (week 4).

Documentary Videos

In order to standardize for the amount of “training” time engaged in by participants across all study groups, the SCT and Control groups were provided with access to 18 documentary videos over the four-week training period. The SCT groups were instructed to watch one 10-minute video segment prior to each SCT task, while the Control group was instructed to watch one 15-minute video segment to comprise each “training” session. Segmented video clips from the Netflix™ documentary series “One Planet” (Fothergill, et al., 2019) were created by the experimenters for each of the 18 sessions following similar protocols used by Zering et al. (2017). To ensure participants attention was actively on the documentary video task, participants were instructed to monitor the audio content and record, on their log sheet, the number of times they heard specific words (e.g., water, grass) on the video.

Secondary Measures

International Physical Activity Questionnaire (IPAQ)

An abridged version of the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) was used to verify study eligibility (i.e., engaging in >60 minutes of MVPA weekly) and assess moderate to vigorous physical activity (MVPA) at each study session. For each of moderate-intensity and vigorous-intensity physical activity, participants indicated the number of days in a typical week (familiarization session) or in the past seven days (pre-, mid-, post-training sessions) they engaged in any activity at that intensity as well as how many minutes per day (on average) they engaged in each activity.

Mental Fatigue

Mental fatigue was assessed using a digital version of a mental fatigue visual analogue scale (MF-VAS; Brown & Bray, 2017) presented on the LimeSurvey platform. Participants completed the digital MF-VAS by moving a "slider" (using their cursor and left mouse click) on a horizontal line presented on a computer screen anchored on the left side with 0 (energetic/ no fatigue) and 100 (worst possible fatigue) on the right side, to indicate their current state of mental fatigue. Participants were instructed to move the slider to the point on the line they felt best represented their current state of mental fatigue. The slider also provided participants with a pop-up visual number corresponding to the position of the slider on the scale (e.g., if the slider was exactly half-way on the scale, participants would see the number 50). Mental fatigue scores were recorded as the number (between 0-100) at which the participant moved the slider.

Procedure

Prior to the familiarization/intake session, participants were assessed for exclusion criteria: medical contra-indicators for moderate to strenuous physical activity and upper body resistance exercise (using the 7-day physical activity recall questionnaire [PAR-Q]; Thomas, et al., 1992), normal vision (i.e., not colour-blind, for Stroop task), and exercise history (< 60 minutes of MVPA/ week). Participants who met eligibility criteria were provided (via email) with warm-up and training resources (links to online videos) to perform a high plank task and scheduled to take part in four remote-based Microsoft Teams™ testing sessions; each lasting approximately 45 minutes and separated by one week (familiarization to pre-training) or two weeks (pre- to mid-training, mid- to post-training). Sessions were scheduled at approximately the same time of day and in a location where they could complete the study activities comfortably and without distraction.

At the initial (familiarization) session, participants were provided with a summary of the study protocol and gave informed consent. Participants then completed a demographic survey, the IPAQ (Craig et al., 2003), and the high plank task familiarization protocol. After completing the initial session, a second (pre-training) session was scheduled for 7 days later.

During the second session, participants completed the incongruent Stroop task protocol followed by the high plank endurance task. Upon completion of the high plank endurance task, they were randomized to one of the SCT (n = 15), SCT+BET (n = 13), or control (n = 11) groups. Participants assigned to the SCT and SCT+BET groups were provided with the handgrip training device, which was dropped off at their home mailbox by the researcher. All participants were requested to avoid deviating from their normal patterns of physical activity (except for the handgrip exercise for the SCT+BET and SCT groups) for the proceeding four-weeks. During the four-week period, participants completed their assigned training protocol.

Two- and four-weeks after the second session, participants engaged in their third (mid-training) and fourth (post-training) sessions, respectively. During each session, participants performed the incongruent Stroop task protocol followed by the high plank endurance task protocol. Upon completion of the high plank endurance task during the fourth session, participants were debriefed and thanked for their contribution to the study. Financial compensation was provided to participants upon completion of the study via electronic fund transfer.

Statistical Analyses

Descriptive statistics of the study variables were computed. Analysis of Variance (ANOVA) or Chi-squared tests were computed to assess between groups for the measured covariates. One-way ANOVAs were computed to assess differences in training adherence and average change in mental fatigue during training sessions. A 3 (Group) X 3 (Session) mixed factorial ANOVA was used to assess the change in mental fatigue scores (Post-task – Pre-task) for the incongruent Stroop task.

To test hypotheses 1 and 2, separate analysis of co-variances (ANCOVAs) at Mid-, and Post-training sessions, with pre-training TTF scores modelled as a covariate, were computed to assess if there were significant improvements in high plank TTF comparing the SCT or SCT+BET groups, respectively, to Control.

To test hypothesis 3, at Mid-, and Post-training sessions, separate ANCOVAs with pre-training TTF scores modelled as a covariate, were computed to assess if SCT+BET significantly improved high plank TTF compared to the SCT group.

To assess group differences in change in RPE over high plank trials, following a protocol described by Blanchfield et al. (2014) and di Fronso et al. (2020), isotimes were computed. To compute isotimes, TTF for the shortest high plank task was identified and used as 100% isotime for all comparisons. The start of each high plank task served as 0% isotime for all comparisons. The expired duration from 0% to 100% isotime was halved to identify the 50% isotime. Similarly, the duration from 0% to 50% was halved to determine 25% isotime and the mid-point between 50% and 100% served as the 75% isotime. RPE values at 0%, 25%, 50%, 75%, and 100% were selected based on the participant's RPE value reported at closest temporal proximity to each isotime. If two RPE values were equidistant from the isotime, the higher RPE value was selected. Participants with less than five separate RPE data points (TTF < 80 seconds) were not included for analysis.

To test hypotheses 4 and 5 evaluating the potential effects of SCT and SCT+BET on RPE during the high plank endurance tasks, analyses consisted of separate 2 (SCT – Control group;

SCT+BET – Control group) X 2 (Pre-, Mid-training; Pre-, Post-training) X 5 (0%, 25%, 50%, 75%, 100% RPE iso-time) mixed factorial ANOVA. RPE scores at the five iso-times were treated as the repeated measures dependent variable.

Primary diagnostic measures were assessed prior to performing each analysis. The sphericity assumption was evaluated using the Mauchly test. Greenhouse Geisser correction for degrees of freedom was applied in case of non-sphericity. The homogeneity of variance assumption was measured using the Bartlett test or Levene's test for ANCOVAs or repeated measures ANOVAs, respectively. The homogeneity of regression slopes was measured by performing an ANOVA test assessing the interaction of the factorial variable and covariate on the dependent variable. The normality assumption was measured using the Shapiro-Wilks test. Following recommendations by Cohen (1983) and Harris et al. (1971), a linear regression model and its respective primary diagnostic measures were performed for calculations when violations of the homogeneity of variance or the homogeneity of regression slopes were present. No alternative corrections were made for violations of normality as ANOVAs are robust to violations of normality (James et al., 1997). The significance level for all tests was set at 0.05. All statistical analyses were performed using R™ (2022.02.3, RStudio, PBC)

Results

Data screening

After study randomization, two participants were moved from the SCT+BET group into the SCT group due to technological issues with acquiring and using the SOMA NPT app. Two participants were moved from the SCT group to the Control group when they failed to receive the handgrip devices necessary for SCT. Prior to the start of training, one participant ($n_{control}$ = 1 [1 male]) dropped out due to a personal conflict. During the training phase of the study, four participants (n_{SCT} = 1 [1 female]; $n_{SCT+BET}$ = 1 [1 male]; $n_{control}$ = 2 [1 female]) dropped out due to personal conflicts, and one participant (n_{SCT} = 1[male]) reported they had not completed their prescribed training and their data were subsequently removed. Thus, composition for each experimental group, for analyses, consisted of: SCT (*n* = 13), SCT+BET (*n* = 10), and control (*n* = 10).

Descriptive Statistics

Descriptive statistics for the measured demographic variables are shown in Table 1. Separate one-way ANOVAs revealed no significant between-group differences for age, $F(1,30) = .737$, $p = .397$, $\eta_p^2 = .023$; year of study, $F(1,30) = 1.856$, $p = .183$, $\eta_p^2 = .056$; height, $F(1,30) = .14$, $p = .711$, $\eta_p^2 = .004$; weight, $F(1,30) = .429$, $p = .517$, $\eta_p^2 = .014$; and MVPA, $F(1,30) = 0$, $p = .987$, $\eta_p^2 < .001$. Chi-square analyses showed no significant between-group differences for sex, $\chi^2 = .888$, $p = .641$, $\varphi = .164$, supporting the success of the randomization procedures.

Table 1. Descriptive statistics for demographic variables

Measure	SCT+BET		SCT		Control	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***
Age	20.75	3.15	21.42	3.40	22.22	3.27
Height (cm)	167.41	7.75	169.11	11.31	169.01	5.67
Weight (kg)	67.12	11.21	66.24	12.36	64.10	6.32
MVPA (min)	335.00	394.69	295.38	157.50	337.00	290.63
Sex [Male:Female]	[3:7]		[6:7]		[3:7]	

Note. *N* = 33 (SCT+BET *n* = 10; SCT *n* = 13, Control *n* = 10). *SD* = Standard Deviation; MVPA = Moderate to Vigorous Physical Activity

Manipulation Checks

Training Manipulation

Training Adherence. Training adherence (represented as percentage of sessions completed) for individual groups are shown in Table 2. A one-way ANOVA revealed no significant between-group differences for average training adherence, $F(1,30) = .462$, $p = .501$, $\eta^2 = .043$.

Table 2. Training adherence by group represented as percent of sessions complete.

Measure	SCT+BET		SCT		Control	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***
Training Adherence	93.9%	11.6%	88.4%	10.2%	88.9%	6.20%

Note. *N* = 33 (SCT+BET *n* = 10; SCT *n* = 13, Control *n* = 10). *SD* = Standard Deviation

Training Mental Fatigue. Average changes in mental fatigue scores from pre- to post-training (averaged over 18 training sessions) are presented in Figure 3 and illustrate much larger differences in the SCT+BET group compared to the other two groups. Results of one-way ANOVA revealed significant between-group differences, $F(1,30) = 8.112$, $p = .008$, $\eta^2 = .219$. Post-hoc Bonferroni pairwise *t*-tests revealed the SCT+BET group reported significantly greater average changes in mental fatigue compared to the SCT ($p = .001$) and Control ($p = .015$) groups. The difference for average change in mental fatigue between the SCT and Control groups was not significant ($p = 1.0$).

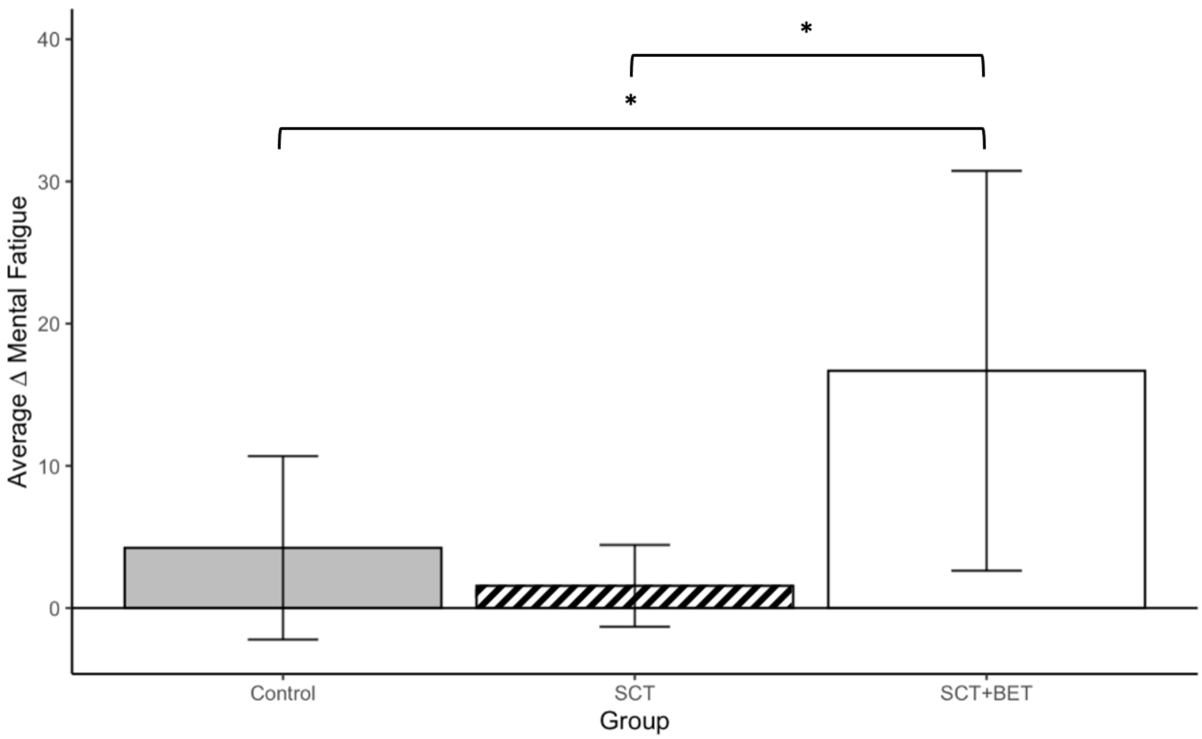

Figure 3. Change in mental fatigue during training (average of post-training MF-VAS – average of pre-training MF-VAS) by training group. * ($p < .05$)

Incongruent Stroop Task Manipulation

Changes in mental fatigue from pre-task to post-task for the incongruent Stroop task by testing session and experimental group are presented in Figure 4. Differences between groups and across sessions were evaluated using a 3 (Group; SCT+BET, SCT, Control) X 3 (Session; pre-, mid-, post-training) mixed ANOVA. Results showed a significant main effect for Session, $F(2,60) = 6.780$, $p = .002$, $\eta_p^2 = .053$. There was no significant main effect for Group, $F(2,30) = .762$, $p = .475$, $\eta_p^2 = .038$; and no significant interaction effect for Group X Session, $F(4,60) = .819$, $p = .518$, $\eta_p^2 = .012$. Tukey post-hoc analyses show an overall decrease in Stroop task-induced mental fatigue from pre-training scores to post-training, $F(2,30) = 10.782$, $p = .003$, $d = .516$.

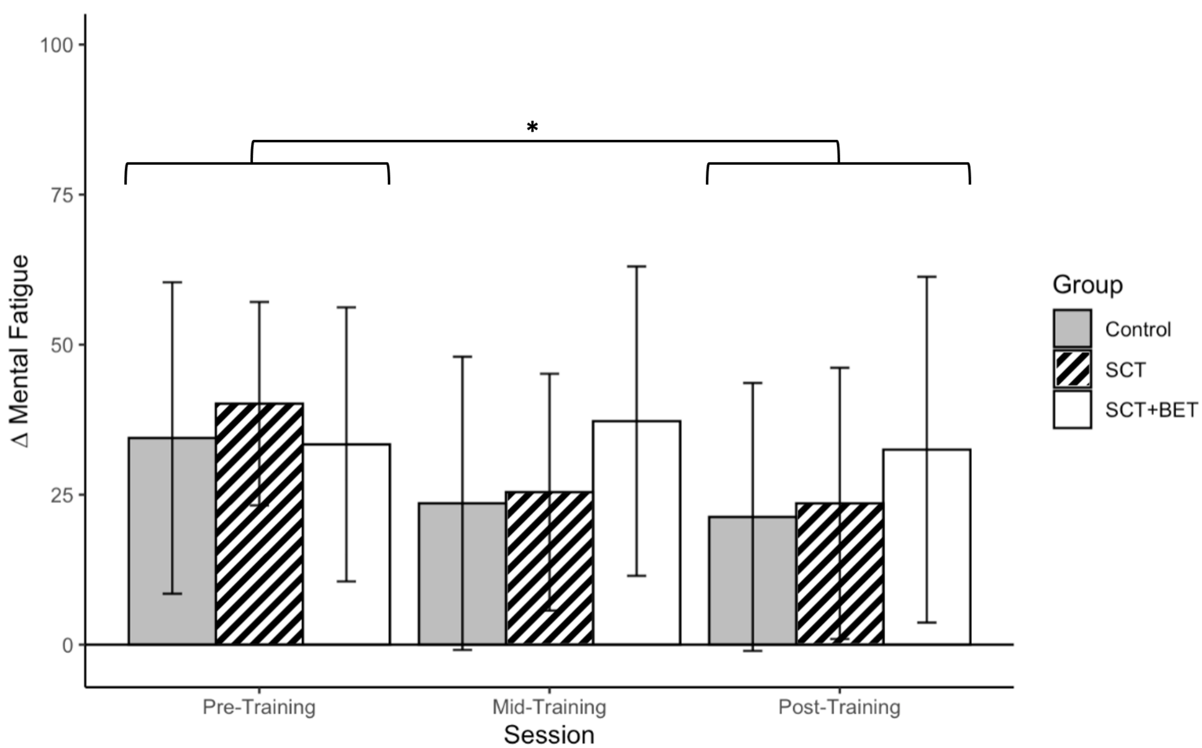

Figure 4. Change in mental fatigue scores (post-task– pre-task) incongruent Stroop task by testing session. * ($p < .05$)

Main Analyses

Raw mean (SD) high plank TTF scores are presented by Group and Session in Table 3.

Table 3. Means and standard deviations for high plank TTF by Group at pre-, mid-, and post-training (in seconds).

Session	SCT+BET		SCT		Control	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Pre-Training	126.18	43.85	139.60	53.21	135.08	77.78
Mid-Training	124.50	36.01	145.80	62.68	131.75	83.94
Post-Training	125.90	40.25	161.15	66.19	114.70	69.13

Note. *SD* = Standard Deviation

Hypothesis 1

SCT – Control at Mid-Training (2-Weeks). The effect of two-weeks of SCT compared to the control group on high plank TTF was evaluated using a one-way ANCOVA comparing group means (SCT, and Control) controlling for pre-training high plank TTF performance. All primary diagnostic results were found to be within acceptable range (Shapiro-Wilks: $W = 0.973$, $p = .696$; Bartlett: $K^2 = 1.018$, $p = .313$; homogeneity of regression of slopes: $F(1,20) = .288$, $p = .597$). Estimated marginal means for high plank TTF by group at mid-training (2-weeks) are presented in Figure 5. Results showed no significant main effect for Group, $F(2,20) = 1.659$, $p = .210$, $d = .617$.

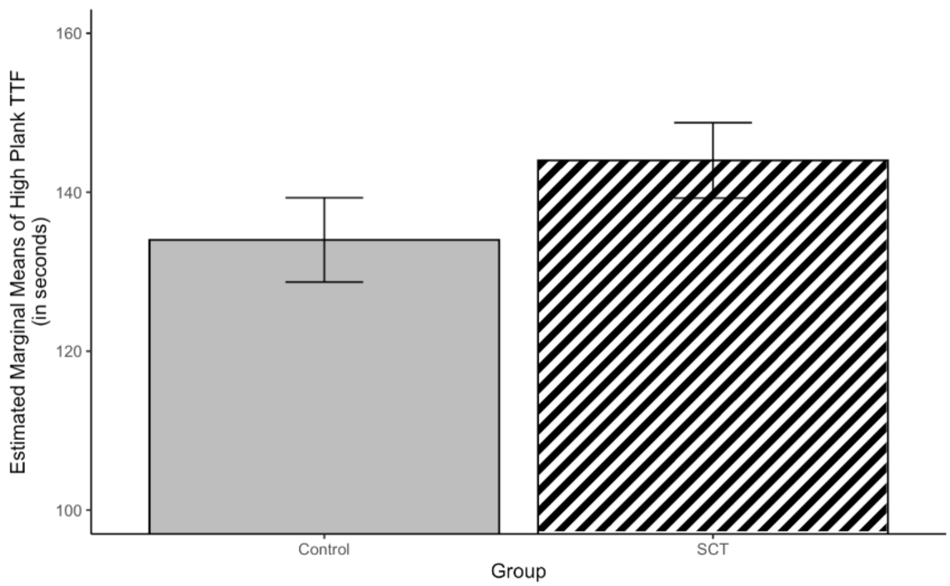

Figure 5. High plank performance comparing SCT and Control groups after two weeks of training. Values expressed are estimated marginal means of Mid-training TTF scores (in seconds) adjusted for Pre-training scores.

SCT – Control at Post-Training (4-Weeks). The effect of four-weeks of SCT on high plank TTF compared to the control group was evaluated using a one-way ANCOVA comparing group means (SCT, and Control) controlling for pre-training high plank TTF performance. All primary diagnostic results were found to be within acceptable range (Shapiro-Wilks: $W = .960$, $p = .473$; Bartlett: $K^2 = .019$, $p = .891$; homogeneity of regression slopes: $F(1,20) = 1.907$, $p = .183$). Estimated marginal means for high plank TTF by group at post-training (4-weeks) are presented in Figure 6. Results show a large and significant main effect for Group, $F(2,20) = 4.637$, $p = .044$, $d = .961$.

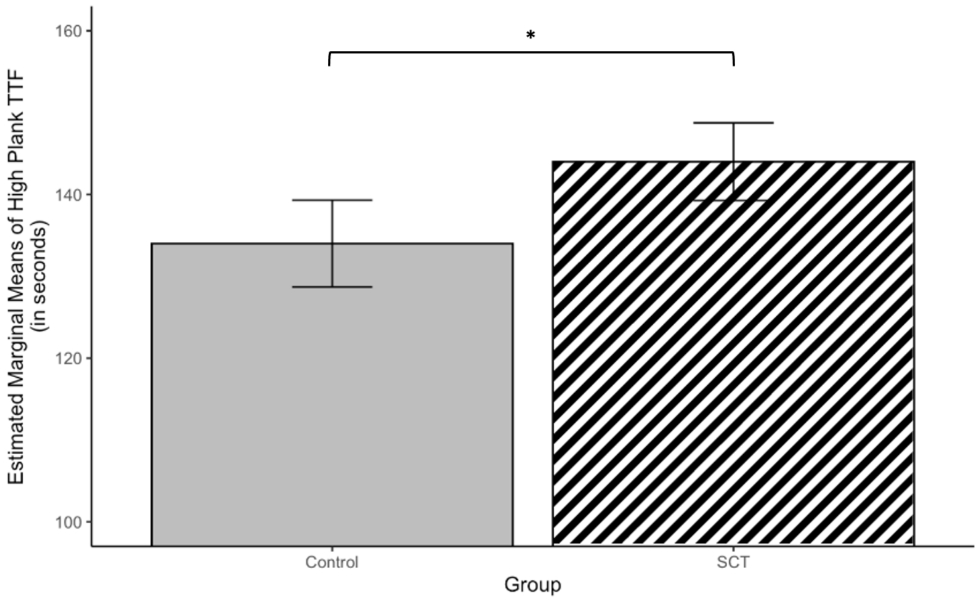

Figure 6. High plank performance comparing SCT and Control groups after four weeks of training. Values expressed are estimated marginal means of Post-training TTF scores (in seconds) adjusted for Pre-training scores. * $p < .05$.

Hypothesis 2

SCT+BET – Control at Mid-Training (2-Weeks). The effect of two-weeks of SCT+BET compared to the control group on high plank TTF was evaluated using a one-way ANCOVA comparing group means (SCT+BET, and Control) controlling for pre-training high plank TTF performance. Primary diagnostic results revealed violations of homogeneity of variance and homogeneity of regression slopes (Shapiro-Wilks: $W = .950$, $p = .310$; Bartlett: $K^2 = 5.788$, $p = .016$; homogeneity of regression slopes: $F(1,17) = 6.720$, $p = .018$). Thus, a linear regression of the high plank TTF at Mid-training on Group X Pre-training high plank TTF was computed. All primary diagnostic results for the linear model were found to be within acceptable range (Shapiro-Wilks: $W = .973$, $p = .696$; Breusch-Pagan: $BP = 3.171$, $p = .205$; Durbin Watson: $DW = 2.239$, $p = .646$; multicollinearity: VIF = 1.005). Estimated marginal means for high plank TTF by group at mid-training (2-weeks) are presented in Figure 7. Results showed no significant main effect for Group, $F(2,17) = .022$, $p = .883$, $d = .057$.

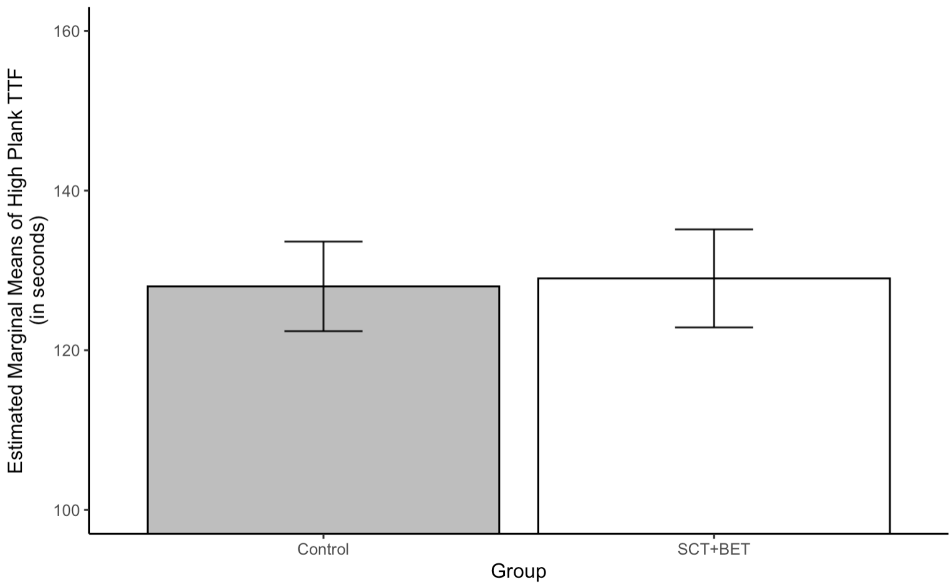

Figure 7. High plank performance comparing SCT+BET and Control groups after two weeks of training. Values expressed are estimated marginal means of Mid-training TTF scores (in seconds) adjusted for Pre-training scores.

SCT+BET – Control at Post-Training (4-Weeks). The effect of four-weeks of SCT+BET on high plank TTF compared to the control group was evaluated using a one-way ANCOVA comparing group means (SCT, and Control) controlling for pre-training high plank TTF performance. All primary diagnostic results were found to be within acceptable range (Shapiro-Wilks: $W = .958$, $p = .508$; Bartlett: $K^2 = 2.382$, $p = .123$; homogeneity of regression slopes: $F(1,17) = 2.435$, $p = .138$). Estimated marginal means for high plank TTF by group at post-training (4-weeks) are presented in Figure 8. Results show no significant main effect for

Group, but a medium positive effect size favouring the SCT+BET group $F(2,17) = .982$, $p = .336$, $d = .461$.

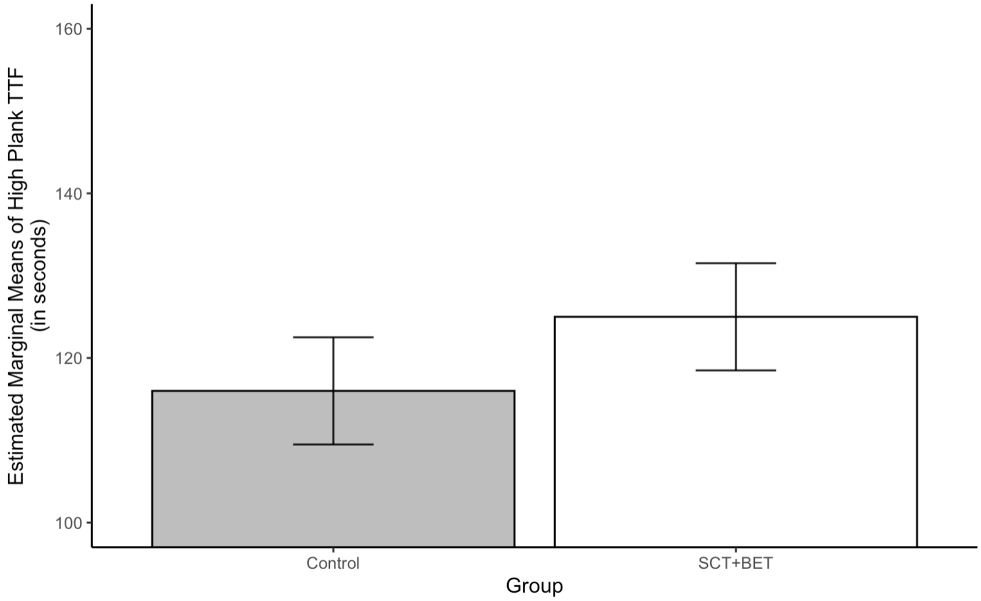

Figure 8. High plank performance comparing SCT+BET and Control groups after four weeks of training. Values expressed are estimated marginal means of Post-training TTF scores (in seconds) adjusted for Pre-training scores.

Hypothesis 3

SCT+BET – SCT at Mid-Training (2-Weeks). The effect of two-weeks of SCT+BET compared to the SCT group on high plank TTF was evaluated using a one-way ANCOVA comparing group means (SCT+BET, and SCT) controlling for pre-training high plank TTF performance. Primary diagnostic results revealed a violation of homogeneity of regression slopes (Shapiro-Wilks: $W = .982$, $p = .919$; Bartlett: $K^2 = 2.853$, $p = .091$; homogeneity of regression slopes: $F(1,20) = 6.622$, $p = .018$). Thus, a linear regression of the high plank TTF at Mid-training on Group X Pre-training high plank TTF was computed. All primary diagnostic results for the linear regression were found to be within acceptable range (Shapiro-Wilks: $W = .982$, $p =$

.919; Breusch-Pagan: *BP* = .844, *p* = .656; Durbin Watson: *DW* = 2.239, *p* = .659; multicollinearity: VIF = 1.005). Estimated marginal means for high plank TTF by group at mid-training (2-weeks) are presented in Figure 9. Results showed no significant main effect for Group, but a medium effect size favouring the SCT group, *F*(2,20) = .922, *p* = .347*, d* = – .464.

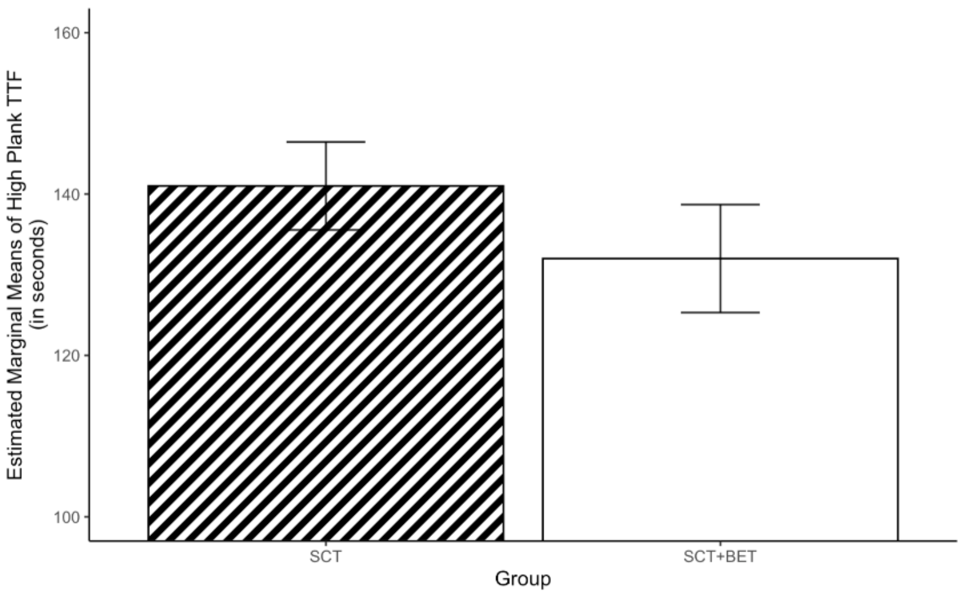

Figure 9. High plank performance comparing SCT+BET and SCT groups after two weeks of training. Values expressed are estimated marginal means of Post-training TTF scores (in seconds) adjusted for Pre-training scores

SCT+BET – SCT at Post-Training (4-Weeks). The effect of four-weeks of SCT+BET compared to the SCT group on high plank TTF was evaluated using a one-way ANCOVA comparing group means (SCT+BET, and SCT) controlling for pre-training high plank TTF performance. Primary diagnostic results revealed a violation of homogeneity of regression slopes (Shapiro-Wilks: *W* = .969, *p* = .668; Bartlett: K^2 = 2.232, *p* = .135; homogeneity of regression slopes: *F*(1,20) = 6.429, *p* = .020). Thus, a linear regression of the high plank TTF at Post-training on Group X Pre-training high plank TTF was computed. All primary diagnostic results for the linear regression were found to be within acceptable range (Shapiro-Wilks: *W* = .969, *p* =

.668; Breusch-Pagan: $BP = 2.062$, $p = .357$; Durbin Watson: $DW = 1.789$, $p = .772$; multicollinearity: VIF = 1.055). Estimated marginal means for high plank TTF by group at post-training (4-weeks) are presented in Figure 10. Results showed no significant main effect for Group, but a medium effect size favouring the SCT group, $F(2,20) = .922$, $p = .347$, $d = -.527$.

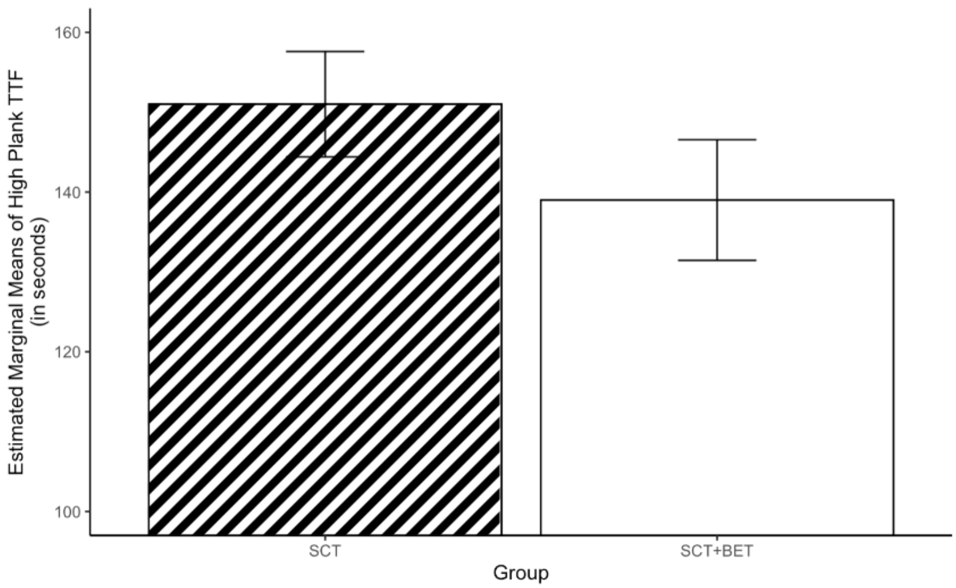

Figure 10. High plank performance comparing SCT+BET and SCT groups after two weeks of training. Values expressed are estimated marginal means of Post-training TTF scores (in seconds) adjusted for Pre-training scores.

Hypothesis 4

SCT – Control at Mid-Training (2-Weeks). The effect of two-weeks of SCT on RPE over isotime comparing Pre-, and Mid-training high plank RPE scores to the Control group were evaluated using a 2 (Group) X 2 (Session) X 5 (0%, 25%, 50%, 75%, 100% isotime) mixed ANOVA. Greenhouse-Geisser corrections for departure from sphericity were applied to the analysis (Shapiro-Wilks: $W = .964$, $p < .001$; Levene: $F(2,84) = .074$, $p = .974$; Mauchly: $W = .101$, $p < .001$, $\varepsilon = .465$). Results showed no significant main effect for Group, $F(1,21) = .714$, p

= .408, η_p^2 = .015; or Session, $F(1,21) = 1.161$, $p = .294$, η_p^2 = .034. There was a significant main effect for Isotime, $F(4,84) = 546.978$, $p < .001$, η_p^2 = .894. There were no significant interaction effects for Group X Session, $F(1,21)$ =.134, $p = .718$, η_p^2 = .005; Group X Isotime, $F(4,84)$ = .296, $p = .828$, η_p^2 = .008; Session X Isotime, $F(4,84) = .475$, $p = .612$, η_p^2 = .008; or Group X Session X Isotime, $F(4,84) = .966$, $p = .384$, η_p^2 = .003. High plank RPE scores over Isotime at Pre-, and Mid-training comparing SCT to Control are presented in Figure 11.

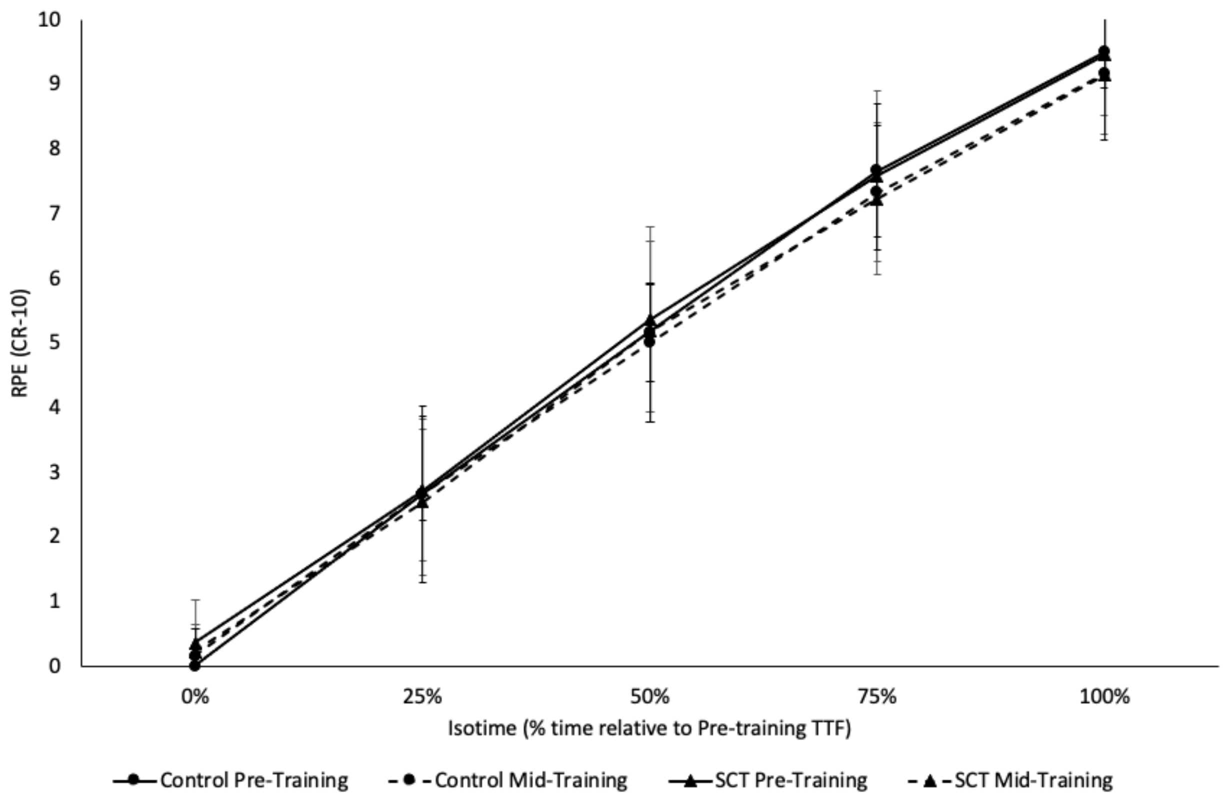

Figure 11. Pre-training to Mid-training high plank RPE at Isotimes of 0%, 25%, 50%, 75% and 100% comparing SCT to Control group.

SCT – Control at Post-Training (4-Weeks). The effect of four-weeks of SCT on RPE over isotime comparing Pre-, and Post-training high plank RPE scores to the Control group were evaluated using a 2 (Group) X 2 (Session) X 5 (0%, 25%, 50%, 75%, 100% isotime) mixed

ANOVA. Greenhouse-Geisser corrections for departure from sphericity were applied to the analysis (Shapiro-Wilks: $W = .949$, $p < .001$; Levene: $F(2,84) = .096$, $p = .962$; Mauchly: $W = .162$, $p < .001$, $\varepsilon = .493$). Results showed no significant main effect for Group, $F(1,21) = 1.61$, $p = .408$, $\eta_p^2 = .029$. There were however significant main effects for Session, $F(1,21) = 6.211$, $p = .021$, $\eta_p^2 = .034$, and Isotime, $F(4,84) = 596.294$, $p < .001$, $\eta_p^2 = .894$. There were no significant interaction effects for Group X Session, $F(1,21) =.892$, $p = .356$, $\eta_p^2 = .005$; Group X Isotime, $F(4,84) = .586$, $p = .632$, $\eta_p^2 = .008$; Session X Isotime, $F(4,84) = .855$, $p = .431$, $\eta_p^2 = .008$; or Group X Session X Isotime, $F(4,84) = .805$, $p = .667$, $\eta_p^2 = .004$. High plank RPE scores over Isotime at Pre-, and Post-training comparing SCT to Control are presented in Figure 12.

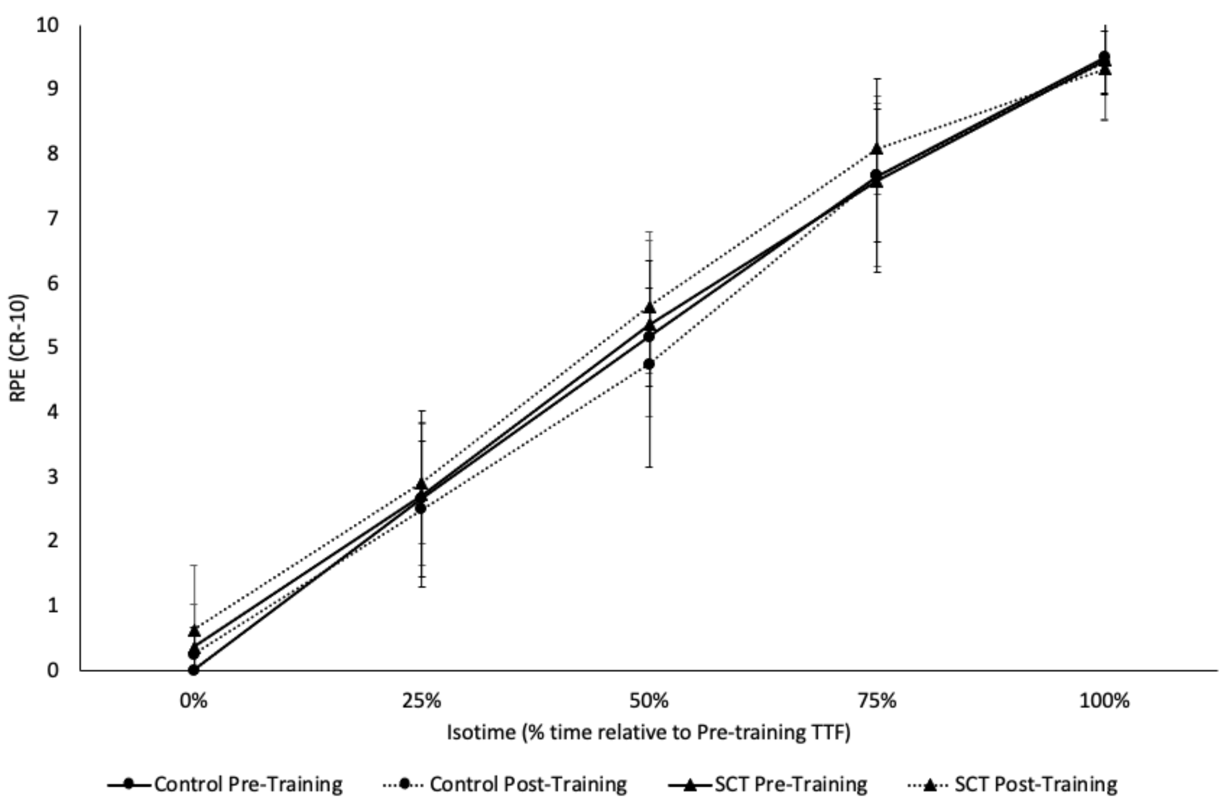

Figure 12. Pre-training to Post-training high plank RPE at Isotimes of 0%, 25%, 50%, 75% and 100% comparing SCT to Control group.

Hypothesis 5

SCT+BET – Control at Mid-Training (2-Weeks). The effect of two-weeks of SCT+BET on RPE over isotime comparing Pre-, and Mid-training high plank RPE scores to the Control group were evaluated using a 2 (Group) X 2 (Session) X 5 (0%, 25%, 50%, 75%, 100% isotime) mixed ANOVA. Greenhouse-Geisser corrections for departure from sphericity were applied to the analysis (Shapiro-Wilks: $W = .939$, $p < .001$; Levene: $F(2,72) = .197$, $p = .898$; Mauchly: $W = .053$, $p < .001$, $\varepsilon = .455$). Results showed no significant main effect for Group, $F(1,18) = 3.233$, $p = .089$, $\eta_p^2 = .050$; or Session, $F(1,18) = 1.230$, $p = .282$, $\eta_p^2 = .013$. There was a significant main effect for Isotime, $F(4,72) = 587.118$, $p < .001$, $\eta_p^2 = .911$. There were no significant interaction effects for Group X Session, $F(1,18) =.002$, $p = .964$, $\eta_p^2 < .001$; Group X Isotime, $F(4,72) = 2.176$, $p = .105$, $\eta_p^2 = .036$; Session X Isotime, $F(4,72) = .577$, $p = .551$, $\eta_p^2 = .006$; or Group X Session X Isotime, $F(4,72) = .502$, $p = .593$, $\eta_p^2 = .005$. High plank RPE scores over Isotime at Pre-, and Mid-training comparing SCT to Control are presented in Figure 13.

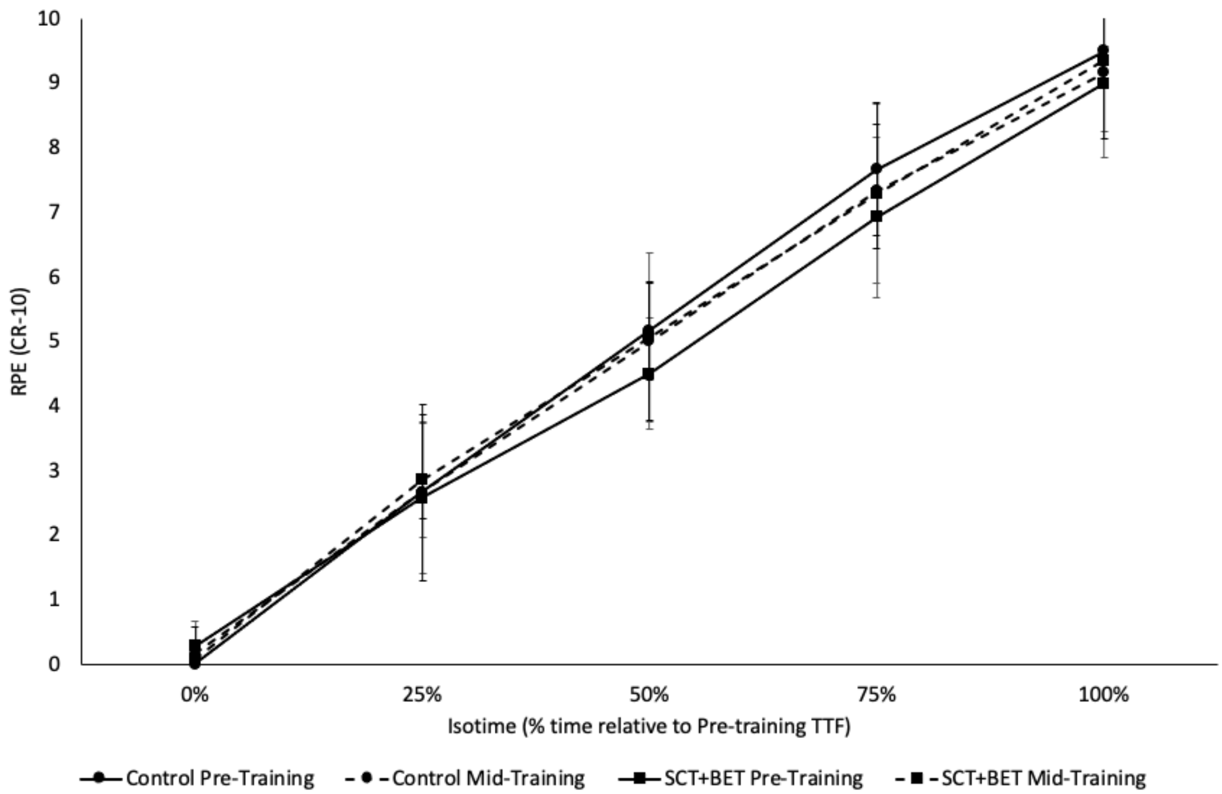

Figure 13. Pre-training to Mid-training high plank RPE at Isotimes of 0%, 25%, 50%, 75% and 100% comparing SCT+BET to Control group.

SCT+BET – Control at Post-Training (4-Weeks). The effect of four-weeks of SCT+BET on RPE over isotime comparing Pre-, and Post-training high plank RPE scores to the Control group were evaluated using a 2 (Group) X 2 (Session) X 5 (0%, 25%, 50%, 75%, 100% isotime) mixed ANOVA. Greenhouse-Geisser corrections for departure from sphericity were applied to the analysis (Shapiro-Wilks: $W = .925$, $p < .001$; Levene: $F(2,72) = .096$, $p = .962$; Mauchly: $W = .053$, $p < .001$, $\varepsilon = .455$). Results showed no significant main effect for Session, $F(1,18) = 3.934$, $p = .063$, $\eta_p^2 = .038$. There were however significant main effects for Group, $F(1,18) = 6.126$, $p = .023$, $\eta_p^2 = .084$, and Isotime, $F(4,72) = 506.511$, $p < .001$, $\eta_p^2 = .905$. There were no significant interaction effects for Group X Session, $F(1,18) =.757$, $p = .396$, $\eta_p^2 = .008$;

Group X Isotime, $F(4,72) = 2.659$, $p = .061$, $\eta_p^2 = .048$; Session X Isotime, $F(4,72) = .460$, $p = .604$, $\eta_p^2 = .005$; or Group X Session X Isotime, $F(4,72) = .265$, $p = .733$, $\eta_p^2 = .003$. High plank RPE scores over Isotime at Pre-, and Post-training comparing SCT to Control are presented in Figure 14.

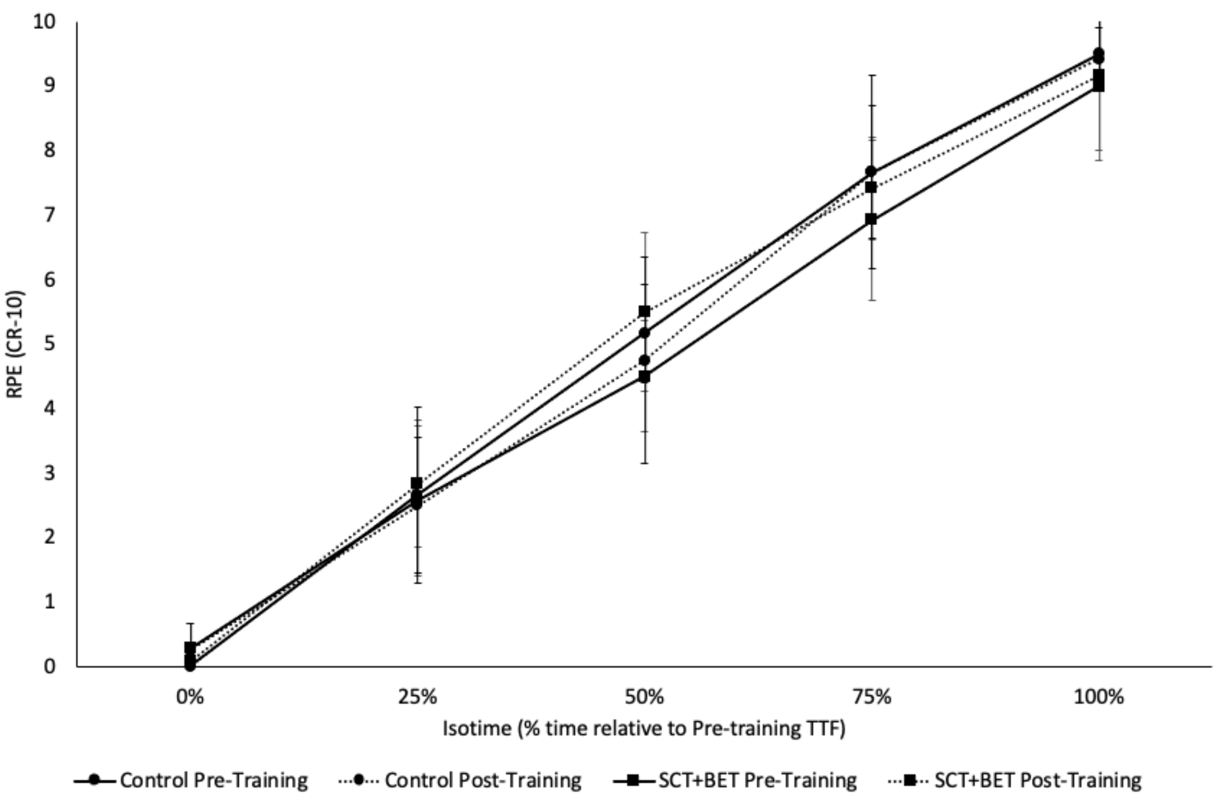

Figure 14. Pre-training to Post-training high plank RPE at Isotimes of 0%, 25%, 50%, 75% and 100% comparing SCT+BET to Control group.

Discussion

The present study investigated the effects of two- and four-weeks of SCT and SCT+BET (using handgrip exercises and cognitive tasks) on performance of an isometric resistance high plank endurance task (measured by TTF) and ratings of perceived exertion (RPE). Contrary to hypotheses, no significant effects were observed for SCT on high plank TTF compared to control after two-weeks of training. However, as hypothesized, there was a large and significant effect for SCT on high plank TTF compared to the control group after four weeks. No effects of SCT+BET on high plank TTF compared to controls or SCT were observed after two- or four-weeks of training. While there were significant effects of group on RPE score between the SCT+BET and Control groups, no significant interaction effects for Group X Session, Group X Isotime, Session X Isotime, or Group X Session X Isotime on RPE after two- or four-weeks of training were observed.

Self-Control Training (SCT) Effects on Performance

The most prominent finding from the present study was the large and significant effect of SCT on high plank TTF performance at four-weeks, compared to control. The present study is the second study to provide evidence supporting the implementation of SCT, in the form of isometric endurance handgrip exercise, as a training technique to improve exercise performance. The significant and large effect of training on high plank TTF supports similar findings from Bray et al. (2015), which showed that SCT had a significant and very large effect on cycling GXT performance ($p < .05$, Cohen's $d = 1.67$).

Although the SCT training effect was significant after four weeks of training, unlike Bray et al. (2015), the SCT effect was not significant after only two-weeks. However, it is noteworthy that there was a medium effect size in the hypothesized direction (Cohen's $d = .617$). While it is not clear why SCT did not significantly influence high plank TTF at two-weeks, possible explanations for the difference in effects at two-weeks between the present study and Bray et al. (2015) may be due to task differences, sample population differences, and trait self-control.

In contrast to Bray et al. (2015), due to COVID-19 and implementing a remote study design, the present study used a high plank task for performance assessment instead of a cycling GXT. While both tasks require self-control, there are several differences between the tasks themselves. One of the prominent differences between a cycling GXT and a high plank task are the different physiological systems they involve, and how those systems are affected by fatigue. A cycling GXT is a cardiovascular exercise. As such, performance is typically limited by ventilatory capacity and not muscular based fatigue or limitations (Boutellier & Piwko, 1992). In comparison, a high plank task is an endurance isometric resistance task. Endurance isometric resistance tasks are primarily limited by motor neuron recruitment patterns and motor neuron fatigue (Enoka & Duchateau, 2008). Thus, the rate of fatigue of the limiting factors for these exercises may differ, and therefore, may have resulted in the differences in effects at two weeks.

In conjunction with the task differences of systems involved, another difference between a cycling GXT and a high plank task is the difference between a graded vs. sustained endurance task. The cycling GXT used in Bray et al. (2015), had participants cycling against an increasing power (50W every 2 minutes) over trial duration to sustain the cycling task. In contrast, the high plank task used in the present study required a sustained and non-changing force over the course of the entire task duration. Thus, differences in the increasing vs sustained force/ power output may have resulted in the differences in effects at two weeks. Possibly then, the differences between the assessment tasks used in the present study compared to Bray et al. (2015) may have resulted in different observed effects at two-weeks.

Another possible reason for the differences between the effects of SCT in Bray et al. (2015) and the present study may be due to sample population differences. For this study, we recruited participants who engaged in a minimum of 60 minutes of MVPA per week; whereas Bray et al. (2015) recruited participants who engaged in less than 120 minutes of MVPA per week. Indeed, when comparing the two samples, the present sample reported much greater quantities of MVPA per week (*M* = 320 min, *SD* = 278) than those in the Bray et al. study. These higher values suggest the average fitness level of participants in the current sample were greater and, consequently, the effects of SCT may not have been as pronounced in the current sample that was more active and more fit.

Given the fact that our sample was more physically active than the sample in the Bray et al. (2015) study, it is also possible that our sample had higher baseline trait self-control, as higher levels of physical activity are correlated with higher levels of trait self-control (Boat & Cooper, 2019). Following this logic, SCT may have been more effective at improving cycling TTF in Bray et al. (2015) compared to high plank TTF in the present study (at two weeks) as people who are lower in trait self-control are more likely to be susceptible to the effects of self-control manipulations (like SCT) compared to individuals with higher trait self-control (Friese & Hofmann, 2009; Hagger et al., 2010a). Nonetheless, while people with higher trait self-control may be less susceptible to the effects of self-control manipulations, that does not mean that individuals with higher trait self-control are *not* susceptible to self-control manipulations. The present study found that SCT does significantly improve high plank TTF after four-weeks.

Considering that at two weeks our study showed a non-significant medium sized effect (Cohen's *d* = .617, Cohen, 1988) and a significant large sized effect (Cohen's *d* = .961, Cohen, 1988) at four-weeks, the present study may indicate that there exists a dose-response relationship between SCT and exercise performance. Indeed, in conjunction with the Bray et al. (2015) findings, the findings from the present study may suggest that there exists a dose-response relationship between SCT and improving exercise performance that may be dependent on trait self-control.

The observation of a possible SCT dose-response relationship that is dependent on trait self-control would support the findings of a recent study by Vermeiren et al. (2021). In that study, the researchers examined the effects of a 12- and 18-month SCT intervention for improving exercise and healthy eating behaviour adherence in children ages 8-18 who were clinically diagnosed as obese. Interestingly, Vermeiren et al. observed a significant ($p < .05$) dose-response relationship between SCT and health outcomes that was dependent on age; specifically, younger children (8-12 years old) showed greater SCT effects. One reason for age being a significant moderating factor for the effects of SCT on health outcomes may be due to the differences in trait self-control exhibited by age (de Ridder et al., 2012). In a meta-analysis by de Ridder et al. (2012), which assessed how trait self-control relates to a wide range of behaviours, age was seen to be a significant moderator of trait self-control, with adolescents having lower trait self-control than adults ($p < .001$). Therefore, as noted above, individuals with lower trait self-control may be more susceptible to the effects of SCT. If lower trait self-control was indeed why younger participants in Vermeiren et al. (2021) were affected by greater doses of SCT, then the findings of the present study, aligned with the findings from Vermeiren et al. (2021), may provide evidence to suggest that there is a relationship between SCT dosage and task performance that is moderated by trait-self control.

To examine if there is indeed a dose-response relationship between SCT and task performance that is moderated by trait self-control, future research should examine whether longer durations of SCT more significantly influence exercise task performance and if baseline trait self-control moderates that relationship. Additionally, within the exercise domain, future research could also explore how SCT in the exercise domain influences different exercise tasks, and how SCT influences individuals with high trait self-control (e.g., professional or semi-professional athletes).

Brain Endurance Training (BET) Performance

Unlike the significant effects observed within the SCT group, the SCT+BET group did not reveal any significant changes in high plank TTF performance. It was initially hypothesized that the strong effects of BET on endurance performance (Staiano et al., 2015, 2019; Dallaway et al., in review) would combine with the strong effects of SCT on endurance performance (Bray et al. 2015). However, contrary to our hypothesis, when comparing the SCT+BET group to the SCT group, it seems as though the combination of BET and SCT may have offset potential positive effects of each type of training.

One explanation for why the SCT+BET group performed worse than the SCT group may be due to the negative effects of mental fatigue on physical task motivation (Boksem & Tops, 2008). Participants in the SCT+BET group were required to perform 10 minutes of a cognitively demanding task prior to performing the SCT handgrip endurance task. In comparison, participants in the SCT group watched a neutral documentary video for 10 minutes before proceeding to perform the SCT handgrip training. Possibly, the greater difficulty of the cognitive task in the SCT+BET group may have resulted in participants in that group being less motivated to perform their physical SCT handgrip endurance task. If participants in the SCT+BET were less motivated to perform the handgrip endurance task, they may have subsequently provided less effort to exert self-control during the handgrip endurance task and failed to maximize the

SCT effects. Alternatively, the inclusion of the cognitively demanding BET tasks prior to the SCT endurance handgrip task may have resulted in an over-exposure to ego depleting stressors on a participant's self-control strength. The over-exposure to ego-depletion on a participant may have exhausted a participants' self-control strength, resulting in worse performance on their subsequent tasks requiring self-control (i.e., the high plank task). This speculation follows Selye's general adaptation syndrome (Selye, 1950), as an excessive amount of stress can result in individual exceeding their ability to adapt to the stressor. When an individual cannot adapt to a stressor, they can enter the "exhaustion phase", resulting in a worse performance against the stressor (Selye, 1950). Therefore, the possible negative effects of the cognitive tasks on the SCT motivation or the detrimental effects of exhausted self-control adaptation may have resulted in the lack of improvements in high plank TTF (and worse performance compared to the SCT group) for the SCT+BET group.

Another possible reason the SCT+BET group saw no significant effects on exercise performance may not be due to task motivation, or self-control exhaustion but rather due to the training dosage used for the BET component of training. For the present study, during each training session, BET consisted of a 10 minute cognitively demanding task performed prior to the SCT handgrip endurance task. The 10-minute duration was selected based on evidence from Brown and Bray (2017) showing that six minutes was a threshold to induce the effects of mental fatigue on performance, as well as due to the limitations of the programming capabilities of the Soma NPT app. Results from the manipulation check confirmed that 10 minutes was effective at mentally fatiguing participants in the SCT+BET training sessions (see Figure 3). However, it is important to note that previous BET research has found significant effects for BET on exercise performance by implementing cognitively demanding tasks for at least 20 minutes during training (Staiano et al., 2015, 2019; Dallaway et al., 2021, in review). Thus, the 10-minute training duration may not have been sufficient to induce the state of mental fatigue needed to observe benefits on exercise performance from BET. More research is needed to explore the dose-response relationship for the cognitive tasks during BET and their effect on performance.

Ratings of Perceived Exertion

It was observed that RPE at isotimes significantly increased throughout the high plank task ($p < .001$), with all participants reaching maximal or near maximal RPE values at 100% isotime. Additionally, when comparing the SCT+BET group to Control for pre-, to post-training (4-weeks), there was a significant main effect for Group ($p = .023$). However, contrary to our hypotheses, there were no significant change in the patterns of RPE by Session; or any of the 2 or 3-way interaction effects after two- and four-weeks of training. Due to no significant changes in high plank TTF for the SCT+BET group at two-, and four-weeks, it is not surprising that their RPE over isotime between pre-, mid-, and post-training sessions showed no significant changes. However, there was a significant change in high plank TTF for the SCT group at four-weeks.

Despite the significant change in high plank TTF for the SCT group at four weeks, there was no significant change in high plank RPE over isotime for the SCT group. This is unusual as, typically, mean RPE increases linearly over time in a proportional manner to TTF (Crewe, et al., 2008; Garcin, et al., 1998). Theoretically then, since the SCT group saw an increase in high plank TTF at four-weeks, they should have also then seen a change in RPE over isotime by session (Group X Session X Isotime interaction). A possible explanation for the lack of change in RPE over isotime during the high plank task for the SCT group may be due to the methodological limitations implemented in the present study. In the present study, we collected participants' RPE at 20 second intervals during the high plank task. However, the average change in high plank TTF for the SCT group from pre-, to post-training was only 21.55 seconds. Therefore, if there were changes in RPE, it is unlikely that a single additional response to RPE would reflect such a change. Indeed, due to the nature of a high plank task being a relatively short task (approximately two-minutes), a 20 second interval for reporting RPE may not have been sensitive enough to detect changes in RPE.

Although there are methodological limitations for assessing RPE, the results of this study may indicate that SCT improves exercise tolerance at the times during an exercise task of greatest physiological difficulty. In the present study, since no significant changes in RPE were observed between 0-100% isotime, changes in RPE for the SCT group must have occurred at >100% isotime. If changes occurred at >100% isotime, and since it is unlikely for an individual's RPE to decrease as a task (requiring a constant power output) duration increases (Garcin et al., 1998), then the changes in RPE would reflect a participant's ability to endure at or near maximal exertion (i.e., RPE ≈ 10) for greater durations. Thus, despite the null findings for SCT and SCT+BET influencing RPE, the present study may indicate that SCT improves an individual's ability to exert self-control at their highest RPE; or in other words, when exerting self-control would be the most difficult. If SCT improves an individual's ability to exert self-control at their highest ratings of effort, then SCT may have practical implications for improving task performance for tasks that operate at higher levels of exertion (e.g., long distance sprinting). Further research with increased RPE sensitivity and tasks that allow increased RPE data collection, as well as research examining the effects of SCT on tasks requiring high levels of exertion are needed to explore these propositions.

Strengths and Limitations

Strengths

There are several strengths and limitations to consider with regards to the present study. An important strength of the study was its expansion of SCT research into the exercise domain. With limited research exploring the effects of SCT on exercise performance, the present study not only contributes to a relatively unexplored field of exercise training, but also provides the first evidence that SCT influences isometric resistance-based exercise performance. A secondary strength of the study was the implementation of a time-matched control group. Unlike the previous research examining the effects of SCT on exercise performance (Bray et al., 2015) that used a passive control group, in our study we implemented a control group that invested the same amount of "training" time over the course of two-, and four-weeks, as the experimental groups. In so doing, our study controlled for potential training "attention" bias or time-investment bias differences between the control and experimental groups.

Another strength of the present study was that, due to institutional COVID-19 restrictions on in-person research, it was performed outside of a lab environment. By performing our research remotely, our findings may be considered to have stronger external validity than has been demonstrated in prior research, and illustrate that SCT effects are replicable and robust when not assessed in controlled laboratory environments. Despite implementing a randomized control trial with virtual assessment sessions (which should not be considered ecologically valid), using remote training and remote assessments of self-control and physical performance meant that participants were not being assessed in a controlled laboratory environment. In turn, participants may have been allowed greater leisure and reduced feelings of judgement. By removing participants from a controlled environment, our study may have reduced some performance bias or extrinsic motivation that a participant may typically demonstrate in a research laboratory. Thus, participants' performance in our study may have more closely paralleled the real-world responses of individuals performing SCT and SCT+BET as they would in an authentic sport training environment.

Limitations

While the present study demonstrated some important strengths, it is not without limitations. Although it can be considered a strength in some ways, one limitation relates to the lack of control involved in performing research outside a lab environment. Due to COVID-19, the present study was performed remotely across a videoconference platform. However, as noted by researchers examining the effects of COVID-19 on social science research quality, when performing research remotely over videoconference platforms, typically there is a decrease in accuracy and judgement capabilities afforded to the researchers (Braun et al., 2020). For our study, we provided participants with clear instructions on how to perform a high plank protocol and monitored their performance over a videoconference platform. Nonetheless, despite our best efforts, monitoring and assessing participants' performance during a high plank over a video camera is limited and may have been prone to errors related to participants' improper form. In comparison, previous self-control research that have implemented planking tasks for assessment have applied rigorous restrictions and rules that control for how a participant performs a plank and have used strict monitoring during testing assessments to control for deviations from those set guidelines (Stocker et al., 2018). Thus, while we may have provided clear instructions and followed similar procedures based on previous research (Stocker et al., 2018), the use of remote assessments may have led to uncontrollable error.

An additional challenge of implementing a remote study protocol is that when assessing participants outside of a laboratory environment, there is a reduction in control over external factors that may influence a participant's performance and self-control (Troll et al., 2022; Varao-Sousa et al., 2018). Unlike in a lab environment, it is impossible to control for background distractions like unwanted noise or people who may interrupt the testing session. For example, during a testing session with one participant, loud street noises from passing cars outside their apartment were audible, to the point where the participant felt the need to apologize for the distracting noise. Distractions can be both detrimental and beneficial for exercise performance (Alberts et al., 2008; MacMahon et al., 2021). Some evidence suggests that when performing exercise, brief distractions reduce the focus on the exercise task at hand, thereby improving performance (Alberts et al., 2008). Other evidence suggests that brief distractions like a loud noise may reduce task motivation and worsen performance (Boman & Hygge, 2000). Thus, due to the uncontrollable nature of remote assessments, measurements of performance during the high plank task assessments may not have reflected each participants' full capabilities.

Another limitation is the lack of control over confounding variables that might also affect exercise performance. For our study, we implemented a randomized control trial. Theoretically, by having a control group, the control group allows us to isolate the effects of training protocols (in the experiment groups) on changes in high plank TTF performance without interference from external factors (Moser, 2020). For the present study it was expected that the high plank TTF for the control group would not change from pre- to post-training, as the control group performed no training that would alter exercise performance. Yet, data from the control group does indeed reveal a negative change in performance. Potentially, the observed change in performance in our control group may indicate that there was an uncontrolled variable in our study that influenced participants' performances (Krauss, 2018). Unfortunately, it is uncertain whether these changes in performance were due to an environmental confounding variable that all groups experienced, or a confounding variable that only one group in our study experienced. Depending on what the confounding variable was, and whether all participants or just participants in the control group experienced that confounding variable would alter how our study results are interpreted.

For example, a potential unexamined confounding variable in our study may have been stress. An increase in stress over time is commonly observed when utilizing an undergraduate study sample population (Pitt et al., 2018). Therefore, in our study, it is likely that as the study progressed, all participants experienced an increase in stress over time. If stress is a confounding variable in our study, it may explain the changes in task performance during the high plank TTF task for the control group. Indeed, if stress was a confounding variable that all groups experienced, then the difference in performance observed between the control group and the SCT group would be solely due to the effects of the four weeks of SCT on high plank endurance performance. Whereas an alternative potential confounding variable in our study may have been motivation. Increased motivation towards an exercise task requiring self-control has shown to significantly improve task performance (Graham et al., 2014). However, a reduction in motivation may also have the opposite effect, potentially resulting in a reduction in performance. Participants in our study, when randomized, were not blinded to the existence of other groups. Therefore, if participants in the control group were aware of being in the control group, they may have been less motivated to perform well within the study. If participants in the control group were less motivated to perform well compared to the SCT and SCT+BET groups, then the observed effects of SCT on exercise performance compared to the control group may not represent the actual effects of SCT on exercise performance.

A further limitation was the implementation of an incomplete 2 X 2 factorial design that did not include a BET group. Due to limited time and resources, and previous research showing no effect of BET training performed without an exercise task on exercise performance (Dallaway et al., in review[b]), we did not include a BET group. By not including a BET group, it is difficult to interpret how BET influenced the SCT+BET group. The results of our study show that the SCT+BET group performed worse than the SCT group. However, if we had included a BET group, it would be possible to infer if the change in performance for the SCT+BET group was due to the BET showing a null or negative effect, or if the SCT+BET operated completely unexpectedly than the individual sum of the two separate training techniques.

Lastly, the small sample size must also be considered a limitation. Based on resource limitations and the effect size from previous SCT research examining SCT on exercise performance (Bray et al., 2015), the power analysis from the WebPower R package for a mixed measures between-subjects design reveal a sufficient sample size number to be N = 31. For our study, after dropouts, our actual sample size was N = 33. Accordingly, our study should have had a large enough sample to detect significant effects for SCT on exercise performance. However, the effect size observed in previous exercise SCT research is not the same size observed in previous BET research. Previous BET research has found smaller effect sizes than previous SCT exercise research (d = .35 vs d = 1.67 respectively; Dallaway et al., 2021; Bray et al., 2015). Therefore, our study was underpowered to detect some of the hypothesized effects. Additionally, due to a small sample size, we were unable to determine if any subject's data would be considered a potential outlier or just an extreme value within a normal distribution. By not having enough data points to consider outliers, certain participants with exceedingly higher or lower changes in performance may have altered our data to reduce the likelihood of detecting an effect.

Based on the aforementioned limitations of the present study, it is imperative that research in this area be continued. Future research examining SCT, BET or similar training techniques should assess state stress and task motivation throughout the duration of the study to reduce potential confounding variables. Controlling for these potential confounding variables in the assessment of a training technique may help reduce uncertainty for how a training technique influences performance. Additionally, to potentially reduce the effects of motivation on task performance, future research should attempt to better blind participants to the differences between groups and should consider implementing a sham control. By blinding participants, and implementing a sham control, not only will the control group be unaware of their status as a control group member, but also, the control group will control for any potential placebo effects that participating in a training group may have. Lastly, although training studies are highly resource-consuming, future research assessing SCT or BET should recruit larger sample sizes and explore dose-response relationships using varied doses of each training technique over longer and shorter durations.

Practical Applications

With appropriate caveats in mind, the present results support potential for SCT to have practical real-world applications. Practicing self-control through SCT may provide practical life benefits to any individual who wishes to improve their self-control. However, specifically related to the findings from the present study, SCT may help improve exercise performance.

Another practical application of SCT may be to help individuals with low trait self-control increase self-control capacity. Individuals with low levels of trait self-control have been shown to experience greater challenges with changing lifestyle behaviours such as adhering to exercise programs (Hagger et al., 2010b). Yet, as observed in the present study, and the Friese et al. (2017) meta-analysis, SCT can improve self-control stamina. While research has yet to test if increased self-control stamina correlates with increased trait self-control, the ability for one to exert self-control for longer durations (self-control stamina) may translate into improvements in trait self-control.

Another possible practical application of SCT may be how it can benefit low- to mid-level athletes who wish to improve their exercise performance. SCT is a simple, time-efficient, and cost-effective training technique that may allow athletes to improve their self-control and their exercise performance. Using an easy-to-perform, daily endurance handgrip squeezing task on a spring-loaded handgrip device, athletes can potentially improve their exercise performance in less than a month. Additionally, while yet to be explored, SCT may have practical applications for athletes when they are injured. Distinct from traditional exercise training routines, SCT does not require significant mobility to enhance performance. As well, SCT is unlikely to result in further injury to an already injured athlete. Thus, SCT may provide athletes with an alternative training technique that they could perform while injured to supplement training loss. For these reasons, coaches and therapists should consider implementing SCT as an alternative training technique for potentially mitigating exercise performance loss for injured athletes.

Conclusion

Self-control is a limited resource, used daily to direct behaviours towards desired end states (Gillibaart, 2018). As self-control is exerted over time, an individual's ego depletion will increase (Baumeister et al., 1998). Within the exercise domain, the greater the individual is ego-depleted, the worse exercise performance will become and the greater the perceived effort will be for performing the exercise task (Brown et al., 2020; Zering et al., 2017). For these reasons, implementing training techniques to improve self-control may help reduce the negative effects of ego depletion, and have substantial benefits for exercise performance. To our knowledge, this study was the first study to investigate if two unique training techniques (SCT and BET) that integrate ego depleting tasks over a prolonged period could be used in concert to significantly improve exercise performance and RPE for a high plank task. Additionally, to our knowledge, this study was the first study to examine the effects of SCT on isometric resistance exercise task performance. Results from the present study found that SCT has a significant and large effect on high plank endurance performance after four-weeks compared to a no-training control group. SCT did not alter RPE, and SCT and BET when performed together were not found to significantly improve high plank endurance performance. The present study provides evidence supporting the implementation of SCT into training programs, but raises questions about the effectiveness of SCT and BET in combination. The effects of SCT and BET on exercise and sport performance should be investigated more thoroughly.

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Appendix A

*Please select the current week of the study that you are completing

Choose one of the following answers

Please choose...

*Please select which day of the week you are completing today

Choose one of the following answers

Please choose...

*Please enter today's date

Format: mm-dd-yyyy

Please enter the time of day at which you are completing the survey?

please specify AM or PM (e.g., 10:38 am)

*MENTAL FATIGUE

Please mark on the line the point that you feel best represents your perception of your current state of **MENTAL FATIGUE.**

Only numbers may be entered in these fields.

Each answer must be between 0 and 100

Before: 0 100

After: 0 100

Please record your Mental Fatigue BEFORE and AFTER completing the cognitive task (watching the 10-minute documentary)

Please also remember to count the number of times you hear the specific word in the video.

After completing the cognitive task on the Soma NPT app, and recording your Feeling States, Mental Fatigue, you may now perform your two consecutive handgrip squeezes.

*How would you rate your level of perceived exertion IMMEDIATELY AFTER completing both of your endurance handgrip squeezes?

Choose one of the following answers

Please choose...

Did you complete 2 consecutive endurance handgrip tasks?

Yes | No | No answer