# SELF-REGULATORY DEPLETION AND PHYSICAL ENDURANCE

# SELF-REGUALTORY DEPLETION, PHYSICAL ENDURANCE AND MUSCLE ACTIVITY: AN EXAMINATION OF DEPLETIO NEFFECTS AND TRAIT SELF-CONTROL AS AN EFFECT MODIFIER

By

COURTNEY CLAYTON, HONS. B. KIN

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree

Masters of Science

McMaster University

MASTER OF SCIENCE (2008) McMaster University

(Kinesiology) Hamilton, Ontario

TITLE: Self-Regulatory Depletion Effects, Physical Endurance and Muscle Activity: An examination of Depletion Effects and Trait Self Control as an Effect Modifier

AUTHOR: Courtney Clayton, Hon B. Kin., (McMaster University)

SUPERVISOR: Steven R. Bray

NUMBER OF PAGES: vii, 93

## Abstract

The limited strength model of self-regulation describes self-regulation as a limited, consumable, and renewable internal resource that is depleted when people attempt to control their emotions, thoughts or behaviours (Baumeister & colleagues 1994; 1996). Evidence indicates a consistent relationship across emotional, mental, and physical domains that task performance in all of these areas draws on the same limited resource and is governed by processes occurring within the central nervous system (Galliot, et al., 2007). The main purpose of this study was to examine the effects of self-regulation depletion on muscle activity (EMG) and physical stamina via an isometric task (ankle dorsiflexion). A secondary objective was to investigate trait self-control as an effect modifier of cognitive self-regulation depletion effects on physical stamina. It was hypothesized that individuals would show a greater decline in isometric endurance performance after undergoing a self-regulatory depletion manipulation compared to when they were exposed to a non-depletion task of similar duration. It was also expected that participants would exhibit greater increases in EMG amplitude after being depleted compared to when not depleted. Additionally, it was hypothesized that people who scored lower on a measure of trait self-control would demonstrate greater depletion effects (i.e., greater pre-to-post performance differences) than those who scored higher on trait self-control. The study was a within-subjects cross-over design involving 31 informed and consenting sedentary university students ($M_{age} = 21.72 \pm 2.57$ years). Participants were stratified by gender and randomized to experience either cognitive depletion (modified Stroop task) or non-depletion (colour word reading task) for their first trial. In each trial, they completed two isometric ankle dorsiflexion endurance trials at 50% of their MVC (predetermined by initial MVC) separated by the cognitive task. Due to an unexpected differential carryover effect of exposure order, analysis of the data was carried out for each testing session, with primary analysis focused on Time 1 as suggested by Grizzle (1965). Time 1 data indicated a trend towards significance ($p = .13$) for performance declines being greater in the depletion group compared to the non-depletion group, and a small effect size of .27 was detected, which is comparable to findings in other related studies (Bray et al., 2008; Muraven & Shmueli, 2006). No statistically significant differences emerged for muscle activity in the tibialis anterior for the depletion group compared to the non-depletion group. Those individuals who scored lower on trait self-regulation showed a non-significant trend towards greater depletion effects on muscular endurance performance than those who scored higher on trait self-regulation ($p = .13$; Cohen's $d = .32$). Results support the limited strength model of self-regulation and the trait self-control as an individual difference factor affecting self-regulation, but raise questions regarding the role of central fatigue effects on muscular activation following self-regulatory depletion.

**Acknowledgements**

It is difficult to overstate my gratitude to my Masters supervisor, Dr. Steven Bray. With his encouragement, inspiration, and great efforts to explain things clearly and simply, he helped make the past two years possible for me. This paper would not have been possible if it were not for his support, endless hours of revision and discussion. Thank you.

I would like to thank John Moroz. He is an asset to the Kinesiology department and his assistance, know-how, advice, and support over the past year has been incredible.

Thank you to my thesis committee, Dr Audrey Hicks, Dr. Kathleen Martin Ginis, and Dr. Peter Keir. I am grateful for your involvement with my thesis project and appreciate your advice and support throughout some of the dilemmas I encountered. I wish you all the very best for the future.

I am so lucky to have made friendships with my student colleagues over the years. We have shared many experiences that I hope will last a lifetime. You guys pulled me through the good time and the well, not-so-good times. Thank you for your support and all the best in your futures.

Lastly, I wish to thank my family, most notably my parents, Sheila and David Clayton. They bore me, raised me, supported me, guided me, taught me, and loved me. To them I dedicate this thesis.

## Table of Contents

**Tables and Figures**

## Literature Review

The ability to pick and choose what behaviours one engages in, or subsequently fails to engage in, is what makes humans distinctly different from other animals (Vohs, Baumeister, Schmeichel, Twenge, Nelson, & Tice, 2008). A range of decisions and choices exist, from very meaningful ones with great personal impact, such as having children or buying a house, to relatively inconsequential ones with little personal effect, like choosing what flavor of gum to buy or what shoes to wear. According to Baumeister, Galliot, DeWall, and Oaten (2006), individuals make decisions and engage in behaviours that are in line with their goals and a set of standards. For example, if an individual has made a goal to cease smoking, s/he would have to change an existing routine of engaging in regular smoke breaks throughout the day, with one that reflects the behavioural goal. In order to achieve the goal of smoking cessation, one would have to override his or her urge (and habitual routine) of engaging in the smoking behaviour. A potential explanation for this behaviour modification lies in the ability to self-regulate and exercise control over one's actions to achieve a goal.

### *Self-Regulation*

The ability to self-regulate refers to the human capacity to exert control over one's actions to achieve a particular goal (Baumeister, Heatherton, & Tice, 1994; Schmeichel & Baumeister, 2004), and can be used interchangeably with the term *self-control*. Self-regulation serves as a mechanism responsible for inhibiting innate, learned, or instinctive responses and replacing them with a desired alternative. One's ability to self-regulate involves a number of different processes carried out in sequence to achieve the goal or conform to a set of standards (Baumeiester, et al., 1994; Heatherton & Baumeister, 1996). This notion of self-regulation is in harmony with the "operate" phase of Carver and Scheier's (1982; 1998) test-operate-test-exit (TOTE) feedback loop theory where the individual performs tasks to alter the current state, including regulating, overriding, and altering patterns of thought, feelings, and behaviour in order to move toward a standard. For example, when trying to lose weight, one might have to override his or her typical behaviour of eating chocolate after dinner to achieve healthier eating patterns as well as monitoring caloric intake throughout the day while working towards an overall goal of losing weight. Thus, the ability to self-regulate requires a conscious effort to avoid the habitual or dominant behaviour and replace it with an alternative that is in alignment with the goal(s).

*Self-Regulation and Health*

Self-regulation has been identified as playing an important role in many problematic personal and societal issues relating to health, such as overweight and obesity (Finkel & Campbell, 2000; Tice & Baumeister, 1997). Specifically, self-regulation or failure at self-regulation contributes to the behaviours associated with poor health practices and outcomes. For example, choosing healthier foods to eat and engaging in health prevention (e.g., using condoms, flossing teeth) and detection (performing self-examinations) activities requires one to override or substitute behaviours he or she is comfortable with (i.e., not performing the behaviour), and replacing them with alternative behaviours (i.e., adopting and maintaining health-promoting behaviours).

One area in which self-regulation plays a particularly important role is within the physical activity domain. Physical inactivity is a major contributing factor to chronic disease development, such as cancer, heart disease, and diabetes (Booth & Lees, 2007). According to Bouchard (2007), physical inactivity contributed to over two million deaths worldwide in 2006. Given the positive physiological and psychological benefits (Graham, Kremer, & Wheeler, 2008; Ren, Semenkovich, Gulve et al., 1994; Warburton, Nicol, & Bredin, 2006) associated with engaging in regular physical activity (>30 minutes/day on most days of the week: Canada's Physical Activity Guide, 2007), physical inactivity has been targeted by a number of public health interventions including school-based programs and mass media campaigns. However, despite considerable investment, data show 51% of Canadians are not sufficiently active to achieve significant health benefits (Canadian Fitness and Lifestyle Research Institute, 2005). Even when people decide to start an exercise program, studies indicate that adherence to exercise programs falls off in a short period of time (Reid, 2006), with more than 50% of individuals dropping out of their exercise program after 6 months (Dishman, 1988). In a recent meta-analysis, it was found that even despite good intentions to participate in weekly exercise bouts, fewer than half of exercisers follow through with their intended exercise behaviour (Hagger, Chatzisarantis, & Biddle, 2002). While many personal, social and environmental factors are linked to physical activity participation (Sallis & Owen, 1999), self-regulation emerges as a variable of interest because adopting and maintaining a program of regular exercise is a complex task that requires a number of merging factors, such as planning, scheduling, motivation, and overriding thoughts, emotions, and behaviours that might deter a person from engaging in exercise.

*Failure of Self-Regulation*

Given the overwhelming proportion of Canadians who are sedentary, the potential role for the breakdown or failure in the ability to override conflicting processes and follow through with a regular exercise routine is of great interest. A number of potential explanations have been reported to help understand why people often fail at self-regulating their behaviour. Of particular interest, Muraven et al. (1998) proposed that self-regulation is comprised of multiple possible contributory factors, including: a) a knowledge structure or schema (e.g., consecutive acts of self-regulation should lead to better self-regulation), b) a skill (e.g., self-regulation is a learned ability to control the self), c) a limited capacity (e.g., has a finite limit), and d) an adaptable form of strength (e.g., can be trained to be more efficient). The last two factors in particular (a limited capacity and an adaptable form of strength) have played a large role in Baumeister and colleagues' extensive line of research investigating self-regulation as a capacity with limited strength (e.g., Baumeister & Heatherton, 1996; Baumeister, Vohs, & Tice, 2007; Baumeister et al., 1994; Muraven et al., 1998; Muraven & Shmueli, 2006; Muraven, & Slessevera, 2003). Together, the evidence suggests that depletion of the self-regulatory reserve is in part, responsible for unsuccessful attempts to override conflicting processes and follow through with goal-directed behaviours.

*The Limited Strength Model*

The limited strength model describes self-regulation as a limited, consumable, and renewable internal resource (akin to muscular energy or strength) that is depleted when people attempt to control their emotions, thoughts or behaviours (Baumeister & Heatherton, 1996; Baumeister et al., 1994; Muraven & Baumeister, 2000). According to the limited strength model, when acts requiring self-regulation are performed, one's capacity to self-regulate is depleted and requires replenishment in order for other behaviours that require self-regulation to be performed successfully. Along these lines, evidence suggests that when an individual performs two or more tasks that require self-regulation simultaneously, performance on one of those tasks is negatively affected on some level (Gilbert, Krull, & Pelham, 1988; Pashler, 1994). Although these findings are consistent with the limited strength rationale, it is still unclear if alternative explanations such as attention control are at least, in part, responsible for the poor performance outcomes.

The limited strength model prevails over other models such as attention, however, when accounting for findings that show after people perform a task that requires self-regulation, performance on subsequent tasks requiring self-regulation is negatively affected (Baumeister et al., 1998; Muraven et al., 1998). In an illustrative study conducted by Vohs and Heatherton (2000; Study 2), chronic dieters were exposed to a high temptation condition (tempting snacks placed next to the individual) or a low temptation condition (tempting snacks placed across the room) while watching a video. Both groups were told they could help themselves to the snacks placed in the room while watching the video. After the participants watched the video they were taken to another room to perform an unsolvable anagram task and the time each participant persisted at the anagram task acted as the dependent measure. They found that the individuals in the high temptation condition persisted for a shorter period of time when performing the unsolvable anagram task than the individuals in the low temptation condition. They interpreted these findings as showing that people who invested greater self-regulation to avoid eating the tempting snacks (i.e., a behaviour they would normally engage in if not on a diet) were less effective at self-regulation later on. Thus, engaging in just one act of self-regulation depleted the limited strength resource that would have been needed to perform better on the second task requiring self-regulation.

In a related study (Vohs & Heatherton, 2000, Study 3) female chronic dieters who were asked to suppress their emotions while watching an emotionally-engaging video consumed more ice cream in a taste-and-rate task than dieters who were given no instructions other than to watch the same video. Results from this study support the notion that when dieters who are already exerting self-regulation are required to suppress their emotional responses, self-regulation in an unrelated domain (eating ice cream) is negatively affected.

In another study by Muraven, Collins and Nienhaus (2002), the investigators examined the applicability of the limited strength model to the regulation of alcohol consumption. They recruited male social drinkers and subjected them to either a high self-regulation depletion condition where the participants were asked to suppress the thought of a white bear or a control condition in which they solved simple arithmetic problems (i.e. no depletion). Afterwards, the men in both conditions were then asked to sample and rate different brands of beer. The amount of free beer consumed in the "taste-and-rate" test acted as the dependent measure as regulating one's alcohol consumption demands self-control (i.e., depletes self-regulation). In order to keep the participants motivated to limit their consumption of the available beer, they were told that they would be taking a driving test at the end of the session. In line with the study's predictions, the participants who were in the high depletion group (thought-supression) consumed more beer than those in the control condition. Thus, when people are required to suppress their normal behavioural, emotional, or cognitive responses, their abilities to self-regulate their performance on other subsequent and unrelated tasks is impaired (Baumeister, Muraven, & Tice, 2000).

Although manipulations of self-regulatory strength based on the limited strength model have targeted a variety of tasks, physical performance has also received limited attention. Muraven and colleagues (study 1; 1998) examined physical stamina using an isometric handgrip endurance task as a behavioural outcome that incorporated self-regulation subsequent to an emotion-suppression task. In that study, individuals squeezed a handgrip exercise device for as long as possible to provide a baseline score of physical stamina. They were then divided into groups who received instruction to show no emotion at all or increase their emotional response, while a third group was given no instruction when watching an emotional video depicting sea turtles dying from exposure to fallout from nuclear weapons testing. Following the video, they repeated the handgrip endurance exercise again. Results revealed that individuals who received instructions to show no emotion at all or to increase their emotional response while watching an emotionally disturbing video prior to performing the handgrip exercise experienced a greater performance decline in physical endurance than those given no instruction prior to watching the video.

In a similar study of physical stamina, Muraven and Shmueli (2006) also examined isometric handgrip exercise endurance among social drinkers. Each participant was required to sniff both water and alcohol (but not provided the opportunity to drink the beverage) before performing the handgrip task. They found that physical performance was poorer after sniffing alcohol (depletion task) than after sniffing water, suggesting that resisting the urge to drink after sniffing the alcohol depletes their self-regulatory reserve, leaving participants with less to draw on for subsequent self-regulatory tasks. However, this study departed from the traditional depletion paradigm in that raw performance scores were assessed, measured as seconds each participant sustained the isometric handgrip task, rather than changes in performance following the different manipulations. This is important to consider because no baseline measure of handgrip was assessed to contrast performance in the depletion or no-depletion conditions.

Together the evidence indicates a clear and consistent relationship across the emotional, mental, and physical domains of self-regulation that task performance in all of these areas appears to draw on the same limited resource. What remains in question, however, is the location, structure and mechanisms of the self-regulatory strength reserve. According to Gailliot and colleagues (2007), the self-regulatory strength reserve is located in the prefrontal cortex, where complex executive control processes such as memory, decision making, and emotion regulation occur. Thus, all acts of self-regulation are governed by processes that occur in the central nervous system, but to what extent do these processes impact what is occurring at the peripheral level while engaging in physical tasks requiring self-regulation?

*Support for Self-Regulatory Depletion and Muscle Activity*

As discussed above, regardless of the self-regulatory domain (e.g., emotional, cognitive, and physical) a growing body of evidence identifies a common and limited resource from which these self-regulatory tasks draw from. While that research stems from the tradition of psychological science, complementary studies are found in the stress and workplace ergonomics literature examining similar processes during multitasking situations. For example, MacDonell & Keir (2005) examined maximal shoulder flexion and abduction alone, and in combination with: a) additional submaximal grip force, b) a mental loading task (i.e., the Stroop colour word task), and c) the grip force and mental loading together. This study showed that when the Stroop colour word task and gripping task were performed simultaneously with a test of maximal isometric shoulder exertions, there was a significant decrease in shoulder moment and muscle activity compared to when the shoulder contraction was performed independently. One interpretation of these findings is the addition of a depleting mental self-regulatory task has negative effects on performance at the level of the muscle.

In a related study, Au & Keir (2007) examined the effects of multitasking on muscle activity in the upper arm by looking at simultaneous sub-maximal shoulder and grip exertions with increased task perception and mental processing demands. They found evidence indicating that mental tasks can provide interference similar to that of an additional physical task. Additionally, when the Stroop colour word task was performed concurrently with shoulder exertion, muscle activity within the trapezius was increased. Together, these findings indicate that performance of the Stroop colour word task in combination with a physical strength test elicits a depletion effect that negatively impacts physical performance suggesting an interplay of central and peripheral factors contributing to physical performance decline. Due to the fact that these studies examined depleting tasks concurrently, the extent to which the mental loading task contributed to less than optimal physical performance as a result of self-regulation depletion remains unclear

In a study of the interplay of central and peripheral factors relating to physical stamina, Bray and colleagues (2008) examined the effect of self-regulation depletion on physical performance and muscle activation. As in the earlier work of Muraven and colleagues (2002), performance difference on an isometric handgrip exercise before and after the participants performed either a depletion task (in this case a modified Stroop task) or a colour word reading task (no depletion) was examined. Muscle activity in the forearm muscles (EMG) while performing the isometric handgrip exercise was also measured. Findings showed the expected performance degradation in the depletion group following self-regulatory depletion and an interesting pattern of results from the EMG data also emerged. Specifically, people in the depletion condition were able to generate the same amount of maximum handgrip force as those who were not depleted, however, when performing the submaximal endurance task they exhibited significantly greater

EMG amplitude at the onset and throughout the sub maximal endurance task. Higher EMG levels are indicative of greater recruitment of motor units and is commonly seen when individuals have undergone a physical task that induces muscular fatigue (Winter, 2005). In other words, the Stroop effect on muscle activation was similar to what would be expected if those people had performed exercise that had caused muscular fatigue in their forearm, yet they had not performed any physical exercise. This interesting finding suggests the potential role of central factors contributing to muscle fatigue subsequent to self-regulatory depletion tasks.

*Central Fatigue in Self-regulatory Failure*

Failure of muscle contraction associated with muscle fatigue is marked by a loss of maximal-force generating capacity. While a number of reasons exist for muscle fatigue, generally speaking, central factors (i.e., central nervous system) and changes in the periphery at the level of the muscle are the overarching reasons for failure of muscle contraction in physical endurance/strength tasks (Gandevia, 2001). The extent to which peripheral and central factors contribute to muscle fatigue remains unclear. The role of central factors, for example, in the muscle's overall inability to continue contraction has received mixed findings, with some reporting little or no central failure (Bigland-Ritchie, et al., 1986b) and others suggesting a significant central activation failure (McKenzie Bigland-Ritchie, Gorman, & Gandevia, 1992). However, there is strong evidence indicative of the significant role of central factors (Kent-Braun, 1999) in muscle failure associated with progressive exercise.

Central factors associated with muscle failure are embraced within the central fatigue hypothesis. According to the "central fatigue" hypothesis, there is a progressive decrease in the voluntary activation of muscle during exercise (Gandevia, 1992). More specifically, the muscle can no longer recruit motor units to sustain the contraction force as a result of processes occurring within the central nervous system. Although central fatigue has not received a great deal of attention within the self-regulation literature, there seems to be some role for central fatigue in explaining the physical performance decrements following self-regulatory depletion in unrelated domains. As mentioned earlier, Bray and colleagues (2008) have provided some initial evidence that the mechanisms underlying self-regulatory depletion effects of muscular endurance tasks produced by investigations of the limited strength model may have considerable overlap with the central fatigue hypothesis. Thus, one of the primary interests of the present study was to further examine the interplay of central and peripheral factors associated with self-regulatory depletion and physical performance.

*The Present Study: Advancements from Previous Literature*

The present study aimed to advance our understanding of self-regulatory depletion effects on physical performance (via an endurance task) and provide additional tests of the limited strength model of self-regulation.

*Isolating muscular self-regulatory depletion effects.* One way in which the present study aimed to expand on existing knowledge was to focus on the effects of self-regulatory depletion on central/muscular fatigue. In the study by Bray and colleagues (2008), muscle activity within the forearm finger flexor muscles utilizing an isometric handgrip task was examined. However, because there are many muscles in the forearm that aid in hand flexion a high degree of "noise" was likely evident in the EMG data in that study due to the contribution of additional muscles to sustain the contraction.

The present study examined ankle dorsiflexion and muscle activation (EMG) of the primary muscle for dorsiflexion: the tibialis anterior. Because the tibialis anterior is the primary agonist muscle involved in dorsiflexion, examination of EMG during fatiguing contractions should provide clearer evidence of muscle effects occurring as a consequence of self-regulatory depletion on the tibialis anterior.

*Within-subjects design.*

Another way in which the current study built on previous research was to employ a within-subjects experimental design. An important consideration when planning and conducting research is achieving adequate power (Cohen, 1988). According to Hallahan & Rosenthal (1996), a researcher can increase the power of a study by increasing the sample size, using more reliable measures, standardizing the experimental procedures, and using a repeated measures design. Thus, using a repeated measures design for the current study would permit each participant to act as his/her own control, increasing the overall power of the study.

To this point, all but one (Muraven & Shmueli, 2006) of the published studies examining the limited strength model of self-regulation has used a between groups experimental design. Although the between subjects approach is appropriate for examining depletion effects, a within-subjects design may have several advantages in terms of examining muscular fatigue effects. For example, skeletal muscles are composed of three types of fibres (type I, IIa, IIb) that vary depending on the action of the muscle (Vander, Sherman, & Lusiano, 2001). The relative fibre type distribution varies from muscle to muscle and from person to person due to a number of factors (e.g., genetics age, endurance training) (Alnaqeeb & Goldspink, 1987; Wang, Zhang, Yu, Cho, Nelson, Bayuga-Ocampo, et al., 2004)). Therefore, individuals who have a greater proportion of type I (slow twitch) fibres might be able to sustain a test of isometric ankle dorsiflexion for a longer duration in the face of fatiguing effects and recover more quickly from the task compared to individuals who have a higher proportion of type II fibres (Vander, et al., 2001). In order to account for the potential difference in fibre type distribution within the tibialis anterior among the participants, a repeated measures design is advantageous.

In addition to the individual physiological differences at the level of the muscle, a large degree of variability associated with the performance task itself is probable. Presumably, some individuals will sustain the contraction for a longer (or shorter) period of time than others, regardless of muscle fibre composition. Some reasons for this might include differing levels of familiarity with the task, ability to learn novel tasks, tolerance of the slight discomfort associated with the task, or sensitivity to the equipment. Each of these factors is likely to contribute to inter-individual variations in performance and muscle activation that would lead to higher levels of random error. Taking these factors into consideration, along with the individual variability associated with the composition of the muscle, a within-subjects experimental design was implemented for the present study.

*Trait Self-control as an Effect Modifier*

Utilizing a within-subjects design allows for a decrease in the amount of random variability in task performance compared to a between-subjects design. However, theory and past research also suggest that systematic variability in self-regulatory depletion effects may be teased out by harnessing individual differences. Specifically, past research (Muraven & Shmueli, 2006; Muraven, Tice, and Baumeister, 1998) has shown mean performance scores for the group of people who undergo the depletion manipulation exhibit overall performance decrements with a substantial degree of variability. In Bray et al.'s (2008) data, for example, while most participants performed worse following self-regulatory depletion, many performed better. Thus, some individuals may have been better at self-regulating during the physical endurance task regardless of being exposed to (and presumably depleted by) the Stroop task. The present study also sought to examine trait self-control as a potential explanation for the resistance some individuals show to acute self-regulatory depletion

Trait self-control refers to a general, yet stable and consistent, characteristic of an individual's ability to exert self-control across time and in different and even unrelated situations (Galliot & Baumeister, 2007). In recent reviews of the literature, trait self-control has been correlated to a variety of cognitive and emotional facets and characteristics in one's life. For example, individuals who report higher levels of trait self-control demonstrate better coping strategies for dealing with anxiety and negative moods, have better grades, avoid addictive behaviours (Finkel & Campbell, 2001), maintain more satisfying and meaningful interpersonal relationships, and avoid impulse control problems (e.g., binge-eating) (Tangney, Baumeister & Boone, 2004). In contrast, individuals who report lower levels of trait self-control are more likely to engage in criminal activity and subsequent imprisonment (Gottfredson & Hirschi, 1990) and are more likely to engage in impulsive spending (Vohs & Faber, 2007).

In addition to relationships that exist between problem behaviours and trait self-control, the predictive utility of trait self-control has been examined in specific cognitive and emotional self-regulatory domains. For example, it was found that trait capacity for self-regulation predicted who would suffer most from thoughts and fears regarding death and death-related anxiety (Galliot, Schmeichel, and Baumeister, 2006). Specifically, people who reported low trait self-control had more thoughts about death and higher death anxiety than those with high trait self-control (Studies 1A-1C: Gailliot et al., 2006).

The predictive utility of trait self-control extends beyond cognitive and emotional tests of self-control and has been applied to behavioural self-regulating domains. For example, a recent study examined trait self-control as a predictor of performance on behavioural tests of self-control (Schmeichel & Zell, 2007). In Study 1, they examined eye-blinking as the dependent measure of self-control. Engaging in eye-blinking is a reflexive behaviour, and resisting the urge to blink requires conscious effort to avoid. Individuals who reported higher trait self-control blinked on average 8.06 times during a 3-minute no-blink test and those who reported lower trait self-control blinked 12.65 times, which was significantly different ($p < .05$). In Study 2, the dependent variable was persistence at a cold pressor test, a task requiring one to override the desire to alleviate the experience of pain. They found that individuals who reported higher levels of trait self-control persisted longer at the painful task than those who scored lower on trait self-control. These findings are encouraging as they provide evidence for varying individual capacities to exert self-regulation when engaging in physical performance tests and can be extended to the current study.

Together, the evidence suggests that individuals who have higher levels of trait self-control show greater success in several aspects of their lives such as academic achievement and social relationships (Tangney et al., 2004) and are able to inhibit a variety of instinctual behaviours (Schmeichel & Zell, 2007). Thus, people who score higher on trait self-regulation may not be affected to the same degree by an acute self-regulatory depletion manipulation as people who score lower on trait self-regulation. The current study examined trait self-control as an effect modifier of self-regulatory depletion effects.

*Study Purpose*

The purpose of the present study was two-fold. The first objective was to examine the effects of self-regulation depletion on physical stamina and muscle activation using an isometric endurance test involving ankle dorsiflexion and a within-subjects experimental design. The second purpose was to investigate trait self-regulation as an effect modifier of cognitive self-regulation depletion effects on physical stamina.

*Study Hypotheses*

The present study had two hypotheses. First, it was hypothesized that individuals would show a greater decline in isometric endurance performance after undergoing a self-regulatory depletion manipulation compared to when they were exposed to a non-depletion task of similar duration. It was also expected that participants should exhibit greater increases in muscle activity after being depleted compared to when not depleted. This hypothesis was in line with previous research by Muraven and colleagues (1998; 2006) and Bray et al. (2008). The second hypothesis was that people who score lower on a measure of trait self-control would demonstrate greater depletion effects (i.e., greater pre-to-post performance differences) than those who score higher on trait self-control. This hypothesis was based on evidence from previous work suggesting the predictive utility of trait self-control in other self-regulatory depletion studies (Gailliot, Schmeichel, and Baumeister, 2006; Schmeichel & Zell, 2007).

## Method

*Participants and Design*

In accordance with Cohen's (1992) recommendations, twenty-six participants per condition were required to achieve 80% power ($\alpha = .05$) to detect a large ES (as seen in Bray et al.'s [2008] performance data) in a two-group analysis of variance. The final sample consisted of 31 sedentary university students (15 males and 16 females). Participants ranged in age from 19 to 29 years ($M = 21.72 \pm 2.57$). Recruitment took place through a web-based advertisement on the university's web page as well as poster advertisements around the university campus. All participants reported engaging in $\leq 2$ days of moderate or vigorous intensity exercise per week over the past 6 months with a mean exercise participation of $1.34 \pm .74$ days per week. All were free of neuromuscular disease, able-bodied, and had colour vision. Participants were stratified by gender and randomized into either a depletion ($n$=16) or non-depletion ($n$ = 15) condition for their first trial and then crossed over to the opposite condition for the second trial.

*Measures*

*Screening Measures*

Once the potential participants contacted the experimenter, they were sent a screening questionnaire via email to determine whether they were eligible to participate in the study. The first section determined whether the individual had any contra-indicating health conditions (i.e., a pacemaker, neuromuscular disease, or diabetes). The second section gauged habitual exercise participation. Finally, the participants completed the PAR-Q (2002), which assessed their health status and eligibility to complete the exercise tasks.

Those individuals who indicated no contra-indicating health conditions, engaged ≤ 2 days of moderate and/or vigorous exercise per week over the past 6 months, and answered "NO" to all of the PAR-Q questions (i.e., were healthy to participate in exercise) were invited to participate in the study.

*Demographic and Anthropometric Information*

Participants completed a questionnaire inquiring about their age, gender, marital status, ethnic background, level of education, year of study, and faculty and program of study. Height and weight were measured using a weight scale and wall chart by the experimenter upon arrival at the laboratory.

*Isometric ankle dorsiflexion task*

The main dependent variable of interest was the change in the amount of time participants maintained an isometric ankle dorsiflexion contraction at 50% of their maximal voluntary contraction (MVC) across two trials of an endurance task. Prior to performing the endurance trial, participants performed two five-second MVCs of isometric ankle dorsiflexion. The greater of the two MVCs was used to determine the 50% MVC target value by calculating the average force across a 1-s window at the peak of the EMG, which was then halved. Participants performed a maximum endurance isometric contraction of their right foot at 50% of their MVC. A custom-built apparatus designed to measure force production during ankle dorsiflexion was used as well as an adjustable chair to ensure hip and knee angles were set at 90° for each participant. The foot force-plate within the custom-built apparatus was set at 20° plantar flexion across all participants allowing maximum force for dorsiflexion (see Van Schaik, Hicks, & McCartney, 1994). The participants received visual feedback via a force-tracing (i.e., a real-time graphed line on a 17" computer monitor) in order to gauge their force output during the endurance task. Participants were instructed to maintain the isometric ankle dorsiflexion endurance task at, or above, the target value for as long as they could. Due to the nature of the task, participants were told they might experience some discomfort and/or pain while performing the task nearing fatigue, but that this was normal and should persist to failure. At any point during the testing, if participants fell short of the target line they were kindly reminded (avoiding encouragement) to try and stay above the line as best they could. Additionally, during this time, participants were not given any feedback in terms of time elapsed or force generation. The trial was complete once the participant failed to sustain the 50% MVC force for longer than 1 sec. The total time the participant maintained the isometric ankle dorsiflexion task contraction above the criterion level served as the physical performance dependent variable. Participants also provided ratings of perceived exertion (RPE) immediately following each trial using Borg's (1998) 10-point CR-10 scale.

*EMG and force recording*

Force output and electromyographic (EMG) amplitude of the tibialis anterior were monitored throughout the MVC tasks and for the entire duration of both endurance trials. Once the leg was free of hair and cleansed with an alcohol swab, two disposable self-adhesive electrodes (1 cm diameter) were affixed below the middle of the muscle belly of the tibialis anterior (to avoid motor end plate of the muscle), separated by approximately 1 inch vertically, , and the ground was placed on the lateral aspect of the lower mid third of the leg. The EMG signals were amplified, digitized, and continually streamed using Powerlab 4/25T data acquisition (ADInstruments, Toronto, Canada) to a PC at a sampling rate of 4kHz. The EMG signals were saved and later analyzed using Chart5™ software (ADInstruments, Toronto, Canada). The forces generated during dorsiflexion and muscle activity in the tibialis anterior were concurrently monitored throughout the entirety of the fatigue trials in order to determine each participant's pattern of force and EMG amplitude. To standardize the force and EMG data across participants, data were sampled during each trial after segmenting the trial into 5, three-second windows representing the first three seconds of the trial (baseline), 1.5 seconds on either side of each quartile (25%, 50%, and 75%), and at the final three seconds prior to task failure at 100%.

*Self-regulatory depletion manipulation*

Consistent with Bray et al. (2008), a modified Stroop color word task (Wallace and Baumeister, 2002) was used as the self-regulation manipulation. In the depletion task, participants were instructed to read aloud from a series of words presented in coloured ink in which the color of the text and the word itself were mismatched. For example, the word "pink" could be printed in orange, red, blue, etc., ink, but not in the colour pink. Participants were required to read aloud the color of the ink and ignore the text of the word itself. In addition, when they encountered a word printed in red ink, they were required to override their initial instruction and read aloud the text of the word (i.e., they read aloud the printed word 'green' or 'blue' and not 'red'). The researcher made note of the participants' performance for the Stroop task. For the non-depletion control task, participants read aloud colored words from a series of printed lists in which the color of the text and the printed words were matched (e.g., the word "blue" was printed in blue ink).

*Trait self-regulation measure*

The Brief Self-Control Scale (Tangney et al., 2004) was used to measure trait self-regulation. The questionnaire is comprised of 13 items measured on a 5-point Likert-type scale anchored from 1 (*not at all*) to 5 (*very much like me*). Included are questions, such as, "I am good at resisting temptation", "I have a hard time breaking bad habits", and "I am able to work effectively toward long-term goals". This measure has shown adequate internal consistency (α=.85) as well as test-retest reliability (.87) (Tangney et al., 2004).

*Manipulation Check Items*

Consistent with previous studies that have examined emotional and cognitive self-regulation depletion (Bray et al., 2008; Muraven & Slessevera, 2003; Muraven et al., 1998), manipulation check measures of fatigue, effort, pleasantness of the task, and mood were administered to participants upon completion of both the depletion and non-depletion control tasks.

*Effort.* Participants reported how much effort they had exerted while performing the modified Stroop task and the reading task anchored from 1 (*little effort*) to 7 (*extreme effort*).

*Fatigue.* Participants reported how tired they felt after performing the modified Stroop task and the reading task anchored from 1 (*not at all*) to 7 (*extremely tired*).

*Frustration.* Participants reported how frustrated they felt while performing the modified Stroop task and reading task anchored from 1 (*not at all frustrated*) to 7 (*extremely frustrated*).

*Pleasantness of the task.* Participants reported how pleasant they found performing the modified Stroop task and the reading task anchored from 1 (*not at all pleasant*) to 7 (*extremely pleasant*).

*Mood.* Participants completed the 16-item Brief Mood Introspection Scale (Mayer & Gaschke, 1988) to measure their current mood and arousal levels. The response scale was modified in order to achieve higher reliability (as recommended by Mayer and Gaschke) from 4 steps to 7 steps. Participants responded to each item on a 1 (*definitely do not feel*) to 7 (*definitely do feel*) Likert-type scale. As per Mayer's (2007) most recent recommendations to score the BMIS, the items were scored using a reverse scoring method on two separate factors that correspond to pleasant vs. unpleasant affect and high and low arousal levels.

*Procedure*

Those participants who were deemed eligible to participate were contacted and scheduled for both of their testing sessions (separated by two full days). The study employed a within-subject crossover design with stratification by gender to either the a) depletion-first or b) non-depletion-first condition with follow-up crossover to the alternate condition for the second testing session. Upon arrival at the laboratory, participants were greeted by the experimenter, given a brief description of the study procedures, and provided informed consent. The participant's height and weight were measured at that time.

The experimenter affixed the electrodes in the appropriate areas of the participant's lower leg and were comfortably seated and placed into the ankle dorsiflexion device. The participant's right leg was strapped into position so that the knee and hip joints were fixed to 90° flexion to avoid any other muscles of the leg aiding in performing dorsiflexion of the foot. Given that the strapped-in leg position was unfamiliar to the participants, they had an opportunity to engage in a familiarization task for approximately 15 seconds in length followed with a 1-minute break, standardized for all participants. The familiarization task and rest time permitted the research assistant to correct any visible problems with the straps or electrode placement in the device as well as correct the participant if they were not performing the task appropriately. Once the participant was prepared to perform the task, they performed their baseline isometric ankle dorsiflexion task consisting of two initial 5-second MVC's, which were separated by 1-minute of rest, and followed by another 2-minutes of rest, and the endurance task.

Following the baseline endurance task, participants engaged in either the control reading task or the modified Stroop task for 6 minutes. Upon completion of the Stroop task or reading task, participants completed questionnaires for 6 additional minutes. During that time they completed demographic information questions (e.g., age, gender, ethnicity, year of study, and program), the manipulation check questionnaire, the Self Control Scale questionnaire, and the Brief Mood Introspection Scale (Mayer & Gaschke,

1988) as seen in Appendix D. To ensure an equal amount of rest time (i.e., 6 minutes), participants who were not finished the questionnaires were interrupted and asked to complete the forms at the end of the session. Participants who completed the questionnaires early were given additional filler questionnaires (e.g., State Mood Questionnaire, etc.) to complete. Participants finished up the session with the second isometric ankle dorsiflexion task identical to the first. Two days later at approximately the same time of day, participants returned and performed the alternate (i.e., depletion or non-depletion) condition.

## Results

*Statistical Treatment of the Data*

*Hypothesis Ia.*

Evaluation of the first hypothesis involved a comparison of change in performance, as measured as the difference in time the participants persisted at the endurance task prior to, and subsequent to engaging in the depletion or no-depletion manipulation. To test this hypothesis performance (number of seconds) on the pre-depletion endurance trial was subtracted from performance on the post-depletion endurance trial to create a change score. A one-way ANOVA was used to compare the mean amount of change from the pre-depletion endurance trial to the post-depletion endurance trial between the depletion and control conditions.

*Hypothesis Ib.*

The second part to hypothesis 1 involved contrasting the EMG in the tibialis anterior between the depleted and control conditions for their post-endurance trial. To determine if there were differences in EMG in the depleted group compared to the control conditions, a 2 (group) X 5 (time) repeated measures analysis of variance (repeated measures on the second factor) was conducted.

*Hypothesis II.*

In order to determine if trait self-regulation acted as an effect modifier of self-regulatory depletion, a tertile split of the trait self-regulation scores was computed for participants in the depletion condition. The tertile split allowed for an "extreme groups" analysis between participants who fall into the outer thirds as "higher" and "lower" trait self-regulators. A one-way ANOVA was used to examine differences in performance change between the pre- and post-endurance trials between the higher and lower trait self-regulators. Examination of trait self-regulation as an effect modifier of depletion effects in the physical performance domain is an exploratory step and secondary to the main purpose of the study, therefore, Cohen's (1992) sample size requirements were set aside for this analysis.

*Data Cleaning*

Prior to analyses, distribution of scores obtained for the dependent measures were examined in order to detect any outliers (~ +/- 3SD). One participant was completely removed from the overall data set due to extreme performance scores. Additionally, two individuals' scores were deleted from the analyses for hypothesis 2 due to the extreme performance scores (> +/- 3SD).

*Demographics*

Demographic information is summarized in Table 1. Comparisons of demographic characteristics by exposure order (i.e., depletion-first and depletion-second) was conducted and results of separate ANOVAs showed that age $F(1,29) = 0.78$, height $F(1,29) = 1.61$, and weight $F(1,29) = 0.36$ did not differ between exposure order ($p>.10$). Thus, the two groups were similar and stratified randomization was effective.

Table 1

*Demographic Characteristics of Study Participants*

| Variable | *N* | *M* | *SD* |
|---|---|---|---|
| Gender | | | |
| Male | 15 | | |
| Female | 16 | | |
| Age | | 21.77 | 2.59 |
| Height (cm) | | 173.66 | 9.40 |
| Weight (kg) | | 74.19 | 18.13 |
| BMI ($kg/m^2$) | | 24.49 | 5.23 |
| Marital Status | | | |
| Single | 29 | | |
| Married | 1 | | |
| Divorced | 1 | | |
| Ethnicity | | | |
| Caucasian | 21 | | |
| Asian | 6 | | |
| Other | 4 | | |
| Current Education Level | | | |
| Undergraduate Student | 23 | | |
| Graduate Student | 8 | | |

*Note:* Scores for continuous variables are represented by means and standard deviations. Scores for categorical variables are represented as total within the sample

*Hypothesis 1a: Individuals will show a greater decline in isometric endurance after undergoing a cognitive self-regulatory depletion task when compared to engaging in no depletion task.*

Mean values for the physical (endurance) performance task contrasting the depletion and non-depletion conditions are presented in Table 2. To examine performance between the depletion and non-depletion conditions, changes in the amount of time (in seconds) participants were able to hold the ankle dorsiflexion isometric contraction at, or above 50% of their initial MVC for the pre- and post-manipulation endurance tasks were calculated as simple change scores (as in Muraven et al., 1998). The obtained scores were compared using a one-way repeated measures ANOVA. Contrary to the hypothesis, no significant difference was found, $F(1, 29) = 2.64, p = .11$, ES = .21, between the depletion and non-depletion conditions in the time-to-failure difference for the endurance task.

Table 2

*Task Performance Scores Contrasting Depletion and Non-depletion Conditions.*

| Condition | *N* | Δ *M* | *SD* | *df* | *F* | *p* |
|---|---|---|---|---|---|---|
| Depletion (raw) | 31 | -14.70 | 26.81 | | | |
| Non-depletion (raw) | 31 | -4.74 | 18.04 | 1,29 | 2.65 | .11 |

*Note.* Δ = time difference measured as post-test time to failure – pre-test time to failure (in seconds).

However, given the study had employed a crossover design, it was necessary to test for treatment/period carryover effects using a 2 (order: depletion or non-depletion first) X 2 (time: pre-manipulation – post-manipulation) mixed ANOVA with repeated measures on the second factor. Unfortunately, that analysis revealed a significant order X time interaction, $F(1, 29) = 12.36$, $p < .01$, representing a differential carry-over effect between the two order streams.

Further inspection of the mean pre- and post-manipulation scores was conducted. Examination of the mean scores at Time 1 and Time 2 indicated between order differences in the pre-manipulation endurance task time-to-failure from Time 1 to Time 2 as seen in Table 3. The depletion-first group experienced a significant $F(1, 15) = 6.43$, $p = .02$, drop in contraction time of more than 20s compared to a non-significant $F(1, 14) = 2.05$, $p = .17$, drop of only 6s for the non-depletion-first group. Due to this confounding factor, further analysis of the data was done as a between-groups analysis at Time 1 and Time 2, focusing primarily on the Time 1 data as suggested by Grizzle (1965).

Table 3

*Task Performance Scores for the Depletion and Non-depletion Conditions Across Trials.*

| | *N* | Pre *M (SD)* | Post *M (SD)* | Δ *M(SD)* | | Pre *M (SD)* | Post *M (SD)* | Δ *M(SD)* |
|---|---|---|---|---|---|---|---|---|
| **Time 1** | | | | | **Time 2** | | | |
| Depletion | 16 | 94.13 (38.31) | 68.37 (17.97) | -25.76 (20.35) | Non-depletion | 73.57 (26.73) | 74.97 (28.51) | 1.41 (16.74) |
| Non-depletion | 15 | 84.41 (22.38) | 73.11 (26.29) | -11.30 (30.11) | Depletion | 77.97 (31.89) | 75.07 (27.45) | -2.91 (13.45) |

*Modified Hypothesis 1a: A greater pre-test to post-test performance decline will be evident among people exposed to self-regulatory depletion (Stroop task) compared to the non-depletion condition.*

*Manipulation Checks*

Manipulation check measures of mental effort, fatigue, frustration, and pleasantness of the task, mood, and ratings of perceived exertion (RPE; Borg, 1998) at Time 1 and Time 2 are presented in Table 4 and Table 5, respectively. A series of between-group ANOVAs indicated significant differences ($p<.05$) in the amount of mental effort $F(1,29) = 25.65$, fatigue $F(1,29) = 7.67$, and frustration $F(1,29) = 4.56$, reported by the participants in the depletion and non-depletion conditions after performing the Stroop or reading task at Time 1. There were no differences in pleasantness $F(1,29) = .31, p = .58$, or in their mood (pleasant-unpleasant scale, $F(1,29) = 1.45, p = .24$ and aroused-calm scale, $F(1,29) = .06, p = .80$) at Time 1. Additionally, no differences were found for RPE between the depletion and non-depletion groups after they completed the pre-manipulation endurance task, $F(1,29) = .46, p = .51$, and the post-manipulation endurance task $F(1,29) = .81, p = .38$.

Additional between-group ANOVAs at Time 2 indicated significant differences ($p<.01$) in the amount of mental effort $F(1,29) = 34.34$ and frustration, $F(1,29) = 56.73$, reported by the participants in the depletion and non-depletion conditions while performing the reading task. There were no differences in fatigue $F(1,29) = 3.81, p = .06$ and pleasantness $F(1,29) = .31, p = .58$,while performing the reading task reported by the participants in the depletion and non-depletion conditions or in their mood (pleasant-unpleasant scale, $F(1,29) = 0.03, p = .87$ and aroused-calm scale, $F(1,29) = .00, p = .97$) after performing the reading task at Time 2. Additionally, no differences were found for RPE between the depletion and non-depletion groups after they completed the pre-manipulation endurance task, $F(1,29) = .3.22$ , $p = .08$, and the post-manipulation endurance task $F(1,29) = .49, p = .49$.

Table 4
*Scores for the Manipulation Check Items for the Word Task, Mood, and RPE at Time 1.*

| Items | Depletion *M (SD)* | Non-depletion *M (SD)* | *df* | *F* | *p* |
|---|---|---|---|---|---|
| Mental Effort | 5.69 (.87) | 3.47(1.51) | 1,29 | 25.65 | .01 |
| Fatigue | 4.13 (1.67) | 2.73 (1.03) | 1,29 | 7.67 | .01 |
| Frustration | 4.50 (1.79) | 3.27 (1.39) | 1,29 | 4.56 | .04 |
| Pleasantness | 2.75 (1.39) | 3.00 (1.07) | 1,29 | .31 | .58 |
| P-U | 73.63 (16.02) | 79.73 (11.69) | 1,29 | 1.45 | .24 |
| A-C | 39.00 (9.52) | 38.20 (7.90) | 1,29 | .06 | .80 |
| RPE( pre) | 8.88 (1.26) | 8.53 (1.55) | 1,29 | .46 | .51 |
| RPE (post) | 9.44 (0.81) | 9.13 (1.06) | 1,29 | .81 | .38 |

*Note:* Depletion ($N = 16$) and Non-depletion ($N = 15$). BMIS (Brief Mood Introspection Scale) was used to measure mood among the participants. Scales used above are: P-U = Pleasant-Unpleasant and A-C = Arousal-Calm. RPE = ratings of perceived exertion (Borg's (1998) CR-10 range: 1-10).

Table 5

*Scores for the Manipulation Check Items for the Word Task, Mood, and RPE at Time 2.*

| Items | Depletion<br>*M (SD)* | Non-depletion<br>*M (SD)* | *df* | *F* | *p* |
|---|---|---|---|---|---|
| Mental Effort | 6.0 (.76) | 2.81 (1.97) | 1,29 | 34.34 | .01 |
| Fatigue | 3.6 (1.06) | 2.69 (1.49) | 1,29 | 3.81 | .06 |
| Frustration | 4.67 (1.50) | 1.44 (.81) | 1,29 | 56.73 | .01 |
| Pleasantness | 2.67 (1.11) | 2.87 (1.20) | 1,29 | .25 | .62 |
| P-U | 80.8 (15.59) | 81.56 (9.72) | 1,29 | .03 | .87 |
| A-C | 36.53 (5.41) | 36.63 (6.64) | 1,29 | .00 | .97 |
| RPE( pre) | 8.73 (1.49) | 9.50 (0.82) | 1,29 | 3.22 | .08 |
| RPE (post) | 9.40 (0.96) | 9.63 (0.81) | 1,29 | .49 | .49 |

*Note:* Depletion ($N$ = 15) and Non-depletion ($N$ = 16). BMIS (Brief Mood Introspection Scale) was used tc measure mood among the participants. Scales used above are: P-U = Pleasant-Unpleasant and A-C = Arousal-Calm. RPE = ratings of perceived exertion (Borg's (1998) CR-10 range: 1-10).

Task performance scores are presented for the depletion and non-depletion groups at Time 1 in Table 6. There was no significant difference between the depletion and non-depletion groups for performance in terms of both the raw performance scores, $F(1,29) = 2.42, p = .13$, (Cohen's $d = .27$), and residualized change scores, $F(1,29) = 1.73, p = .20$, (Cohen's $d = .23$).

Table 6

*Task Performance Scores Contrasting Depletion and Non-depletion Conditions at Time 1.*

| | | Δ | | | | |
|---|---|---|---|---|---|---|
| Condition | *N* | *M (SD)* | *df* | *F* | *p* | *ES* |
| Depletion (raw) | 16 | -25.76 (20.35) | | | | |
| Non-depletion (raw) | 15 | -11.30 (30.11) | 1,29 | 2.42 | .13 | .27 |
| Depletion (res) | 16 | -4.14 (14.23) | | | | |
| Non-depletion (res) | 15 | 4.42 (21.51) | 1,29 | 1.73 | .20 | .23 |

*Note.* Δ = time difference measured as post time to failure – pre time to failure (in seconds). Residualized change scores (res) were calculated by regressing the post-manipulation time-to-failure (dependent variable) on the pre-manipulation time-to-failure (independent variable).

Task performance scores are presented for the depletion and non-depletion groups at Time 2 in Table 7. There was no difference between the depletion and non-depletion groups for performance in terms of both the raw performance scores, $F(1,29) = .63$. $p = .43$, (Cohen's $d = .14$), and residualized change scores, $F(1,29) = .47$, $p = .50$, (Cohen's $d = .12$).

Table 7

*Task Performance Scores Contrasting Depletion and Non-depletion Conditions at Time 2.*

| Condition | *N* | Δ<br>*M (SD)* | *df* | *F* | *p* | *ES* |
|---|---|---|---|---|---|---|
| Depletion (raw) | 15 | -2.91 (13.45) | | | | |
| Non-depletion (raw) | 16 | 1.41 (16.74) | 1, 29 | .63 | .43 | .14 |
| Depletion (res) | 15 | -1.81 (14.66) | | | | |
| Non-depletion (res) | 16 | 1.70 (13.77) | 1,29 | .47 | .50 | .12 |

*Note.* Δ = time difference measured as post time to failure – pre time to failure (in seconds). Residualized change scores (res) were calculated by regressing the post-manipulation time-to-failure (dependent variable) on the pre-manipulation time-to-failure (independent variable).

*Modified Hypothesis 1b. Greater levels of muscle activity will be observed in the depletion group while performing the post-manipulation muscular endurance activity compared to the non-depletion group.*

Force production for the depletion and non-depletion groups was not different during the post-manipulation endurance task ($p$ >.10). Separate analysis between the depletion and non-depletion groups at Time 1 and Time 2 was followed for the same reasons as presented under hypothesis 1a.

Graphic representations of muscle activation (EMG) and force production in the tibialis anterior during the endurance task are presented for Time 1 in Figure 1 and, for Time 2 in Figure 2. The pre-manipulation force production and EMG amplitude are presented in light grey and post-manipulation force production and EMG in black. Force production during the pre- and post-endurance trial for the depletion and non-depletion groups was just above 50% (in line with protocol).

At Time 1, EMG levels during the pre-trial and post-trial were evaluated using separate 2 (condition: depletion vs. non-depletion) X 5 (time: baseline, 25, 50, 75, 100) ANOVAs with repeated measures on the second factor. The pre-trial analysis showed significant main effects for time, $F(1,29) = 129.60$ , $p<.01$, and non-significant effects for condition, $F(1,29) = .86$, $p = .36$, and the condition X time interaction, $F(1,29) = .50$, $p = .49$. The post-trial analysis also showed a significant main effect for time, F(1,29) = 68.63, $p <.001$, and non-significant effects for condition, $F(1,29) = .31$, $p = .59$, and the condition X time interaction, $F(1,29) = 1.20$ , $p = .28$. To further investigate whether the experimental conditions differed at all in muscle activation at any of the separate quartile time points, separate between-group ANOVAs were computed to examine the differences in muscle activation of the tibialis anterior during the endurance trial as seen in Table 8. No significant differences were found for EMG levels in the tibialis anterior during the endurance task between the depletion and non-depletion conditions ($p$>.30).

At Time 2, EMG levels during the pre-trial and post-trial were evaluated using separate 2 (condition: depletion vs. non-depletion) X 5 (time: baseline, 25, 50, 75, 100) ANOVAs with repeated measures on the second factor. The pre-trial analysis showed a significant main effect for time, $F(1,29) = 159.97$ , $p<.01$, and non-significant effects for condition, $F(1,29) = .00$, $p = .96$, and the condition X time interaction, $F(1,29) = .05$, $p = .83$. The post-trial analysis also showed a significant main effect for time, $F(1,29) = 122.94$, $p<.01$, and non-significant effects for condition, $F(1,29) = .43$, $p= .52$, and the condition X time interaction, $F(1,29) = .43$, $p = .52$. To further investigate whether the experimental conditions differed at all in muscle activation at any of the separate quartile time points, separate between-group ANOVAs were computed to examine the differences in muscle activation of the tibialis anterior during the endurance as seen in Table 9. No significant differences were found for EMG levels in the tibialis anterior during the endurance task between the depletion and non-depletion conditions ($p$>.30).

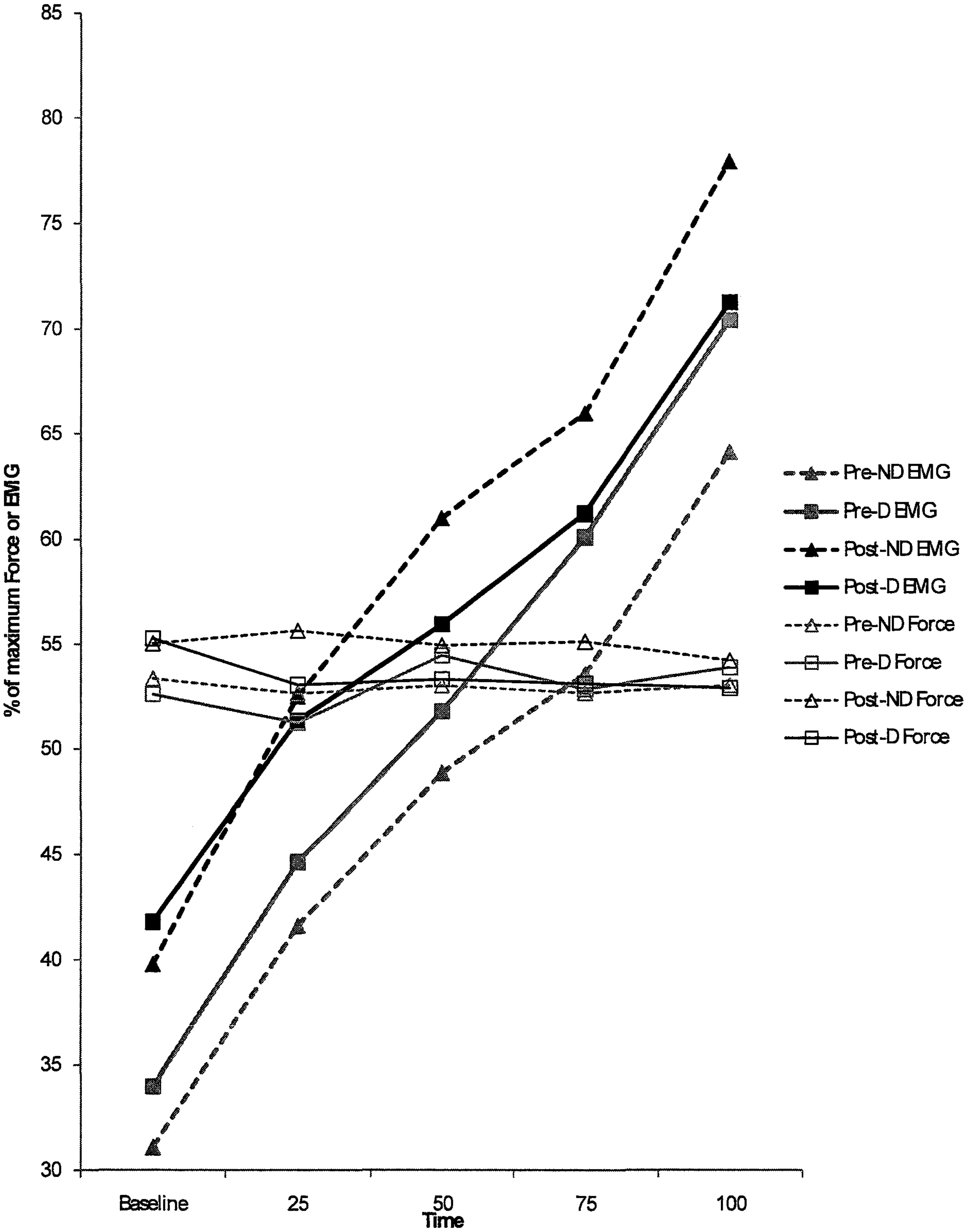


*Figure1.* EMG and force production in the tibialis anterior as a function of maximum voluntary contraction (MVC) during at 50% of MVC during the endurance task pre- and post-manipulation at Time 1.

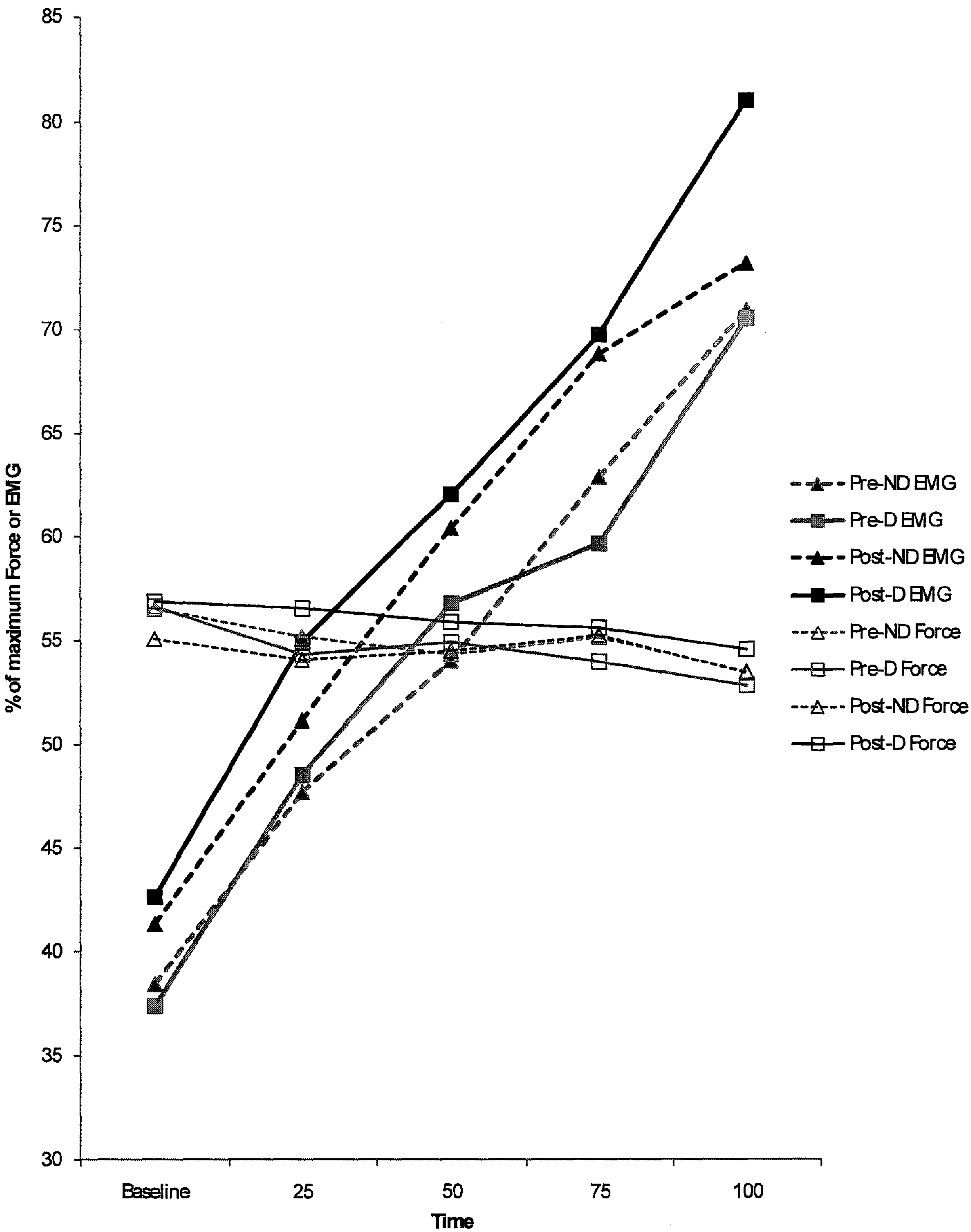


*Figure2.* EMG and force production in the tibialis anterior as a function of maximum voluntary contraction (MVC) during at 50% of MVC during the endurance task pre- and post-manipulation at Time 2.

Table 8

*Muscle Activity (EMG) in the Tibialis Anterior during the Endurance Task at Time 1.*

| | | Depletion | | Non-Depletion | | | |
|---|---|---|---|---|---|---|---|
| | | *M* | *SD* | *M* | *SD* | *F* | *p* |
| Pre | 0 | 37.0 | 13.4 | 31.1 | 6.9 | .56 | .46 |
| | 25 | 44.6 | 12.9 | 41.6 | 8.6 | .58 | .45 |
| | 50 | 51.8 | 15.2 | 48.9 | 12.4 | .35 | .56 |
| | 75 | 60.1 | 18.4 | 53.6 | 15.6 | 1.13 | .30 |
| | 100 | 70.4 | 21.7 | 64.1 | 18.0 | .77 | .39 |
| Post | 0 | 41.8 | 12.6 | 39.8 | 11.5 | .22 | .65 |
| | 25 | 51.4 | 14.5 | 52.5 | 16.4 | .04 | .84 |
| | 50 | 56.0 | 15.2 | 61.0 | 21.3 | .58 | .45 |
| | 75 | 61.2 | 16.0 | 66.0 | 24.6 | .41 | .53 |
| | 100 | 71.3 | 22.5 | 77.9 | 22.7 | .67 | .42 |

*Note:* *F* and *p* values above obtained by a series of one-way ANOVAs.

Table 9

*Muscle Activity (EMG) in the Tibialis Anterior during the Endurance Task at Time 2.*

| | | Depletion | | Non-Depletion | | | |
|---|---|---|---|---|---|---|---|
| | | *M* | *SD* | *M* | *SD* | *F* | *p* |
| Pre | 0 | 37.4 | 7.8 | 38.4 | 12.0 | .08 | .78 |
| | 25 | 48.5 | 8.8 | 47.7 | 12.3 | .05 | .83 |
| | 50 | 56.8 | 15.1 | 54.0 | 13.8 | .29 | .60 |
| | 75 | 59.7 | 11.2 | 62.9 | 12.9 | .56 | .46 |
| | 100 | 70.6 | 14.6 | 70.9 | 17.6 | .00 | .95 |
| Post | 0 | 42.6 | 10.7 | 41.3 | 10.5 | .12 | .71 |
| | 25 | 54.9 | 13.2 | 51.2 | 11.3 | .72 | .40 |
| | 50 | 62.1 | 15.8 | 60.4 | 13.4 | .10 | .76 |
| | 75 | 69.8 | 15.4 | 68.9 | 14.5 | .03 | .87 |
| | 100 | 81.1 | 24.7 | 73.2 | 17.2 | .07 | .31 |

*Note: F* and *p* values above obtained by a series of one-way ANOVAs.

*Hypothesis 2: It is expected that people who undergo self-regulatory strength depletion and who score lower on trait self-regulation will demonstrate greater depletion effects (i.e., greater pre-to-post performance differences) than those who score higher on trait self-regulation.*

Descriptive statistics for the scores obtained on the Brief Self Control Scale (BSCS; Tangney et al., 2004) and performance scores are presented in Table 10. Scores obtained at Time 1 for trait self-regulation were used in the analysis since there was no significant difference between Time 1 and Time 2 scores. A tertile split of the BSCS scores reported by the participants was computed to identify “lower” (or “poor”) and “higher” (or “good”) self-regulators. Results from the one-way ANOVA comparing “lower” and “higher” self-regulators indicated a trend towards significance, $F(1,19) = 2.51, p = .13$, (Cohen’s $d = .32$), for the differences in time-to-failure following self-regulatory depletion.

Given concerns regarding the differential carryover effects of condition presentation order on time-to-failure between the groups, additional analyses were performed using the data at Time 1 as seen in Table 11. There was a trend towards significance, $F(1,9) = 2.84, p = .13$, (Cohen’s $d = .44$) between the “lower” and “higher” self-regulators for change in task time-to-failure.

Time 2 data are presented in Table 12. There was no difference in performance for the “lower” and “higher” self-regulators $F(1,7) = .18, p = .69$, (Cohen’s $d = .15$) at Time 2.

Table 10

*Brief Self-Control Scores (BSCS) and Performance Sores for the Depletion Condition.*

| | Lower BSCS | Higher BSCS | | | | |
|---|---|---|---|---|---|---|
| Variable | *M (SD)* | *M (SD)* | *df* | *F* | *p* | *ES* |
| BSC Score | 32.20 (3.43) | 47.91 (3.65) | 1,19 | 102.97 | .01 | |
| TTF Δ | -16.76 (15.53) | -8.35 (7.99) | 1,19 | 2.51 | .13 | .32 |

*Note.* BSCS = Brief Self-Control Scale; questionnaire is composed of 13 items measured on a 5-point Likert-type scale anchored from 1 (*not at all*) to 5 *(very much like me*). Lower BSC ($N$ = 10), Higher BSCS ($N$=11).

Table 11

*Brief Self-Control Scores (BSCS) and Performance Scores at Time 1.*

| | Lower BSCS | Higher BSCS | | | | |
|---|---|---|---|---|---|---|
| Variable | *M (SD)* | *M (SD)* | *df* | *F* | *p* | *ES* |
| BSC Score | 31 (3.67) | 49 (4.47) | 1, 9 | 51.64 | .00 | |
| TTF Δ | -20.89 (9.34) | -13.47 (5.05) | 1, 9 | 2.83 | .13 | .44 |

*Note.* BSCS = Brief Self-Control Scale; questionnaire is composed of 13 items measured on a 5-point Likert-type scale anchored from 1 (*not at all*) to 5 (*very much like me*). Lower BSC (*N* = 5), Higher BSCS (*N*=6).

Table 12

*Brief Self-Control Scores (BSCS) and Performance Scores at Time 2.*

| | Lower BSCS | Higher BSCS | | | | |
|---|---|---|---|---|---|---|
| Variable | *M (SD)* | *M (SD)* | *df* | *F* | *p* | *ES* |
| BSC Score | 32.75 (4.11) | 50.20 (5.63) | 1,7 | 26.68 | .00 | |
| TTF Δ | -3.55 (7.07) | .54 (18.04) | 1,7 | .18 | .69 | .15 |

*Note*. BSCS = Brief Self-Control Scale; questionnaire is composed of 13 items measured on a 5-point Likert-type scale anchored from 1 (*not at all*) to 5 (*very much like me*). Lower BSC (*N* = 4), Higher BSCS (*N*=5).

## Discussion

The purpose of the present study was to examine the effects of self-regulatory strength depletion on muscle activity (EMG) and physical stamina via a physical endurance task (isometric ankle dorsiflexion). The investigation also examined trait self-control as an effect modifier within the self-regulation depletion and physical performance domain.

The current study implemented a within-subjects crossover design in order to provide a direct comparison of physical performance and muscle activation between the two conditions (i.e., depletion and non-depletion). Initial analysis of the data revealed no statistically significant differences between the depletion and non-depletion conditions for physical performance or for the recorded EMG signals during the task. However, a significant order X time interaction occurred, such that a differential carry-over effect between the two order streams was present, and further analysis of the data proceeded as separate between-groups analyses using the respective Time 1 and Time 2 datasets and focusing primarily on the Time 1 data as suggested by Grizzle (1965). As such, the original hypotheses were modified and due to lower levels of statistical power, interpretational emphases hinged on effect sizes rather than conventional levels of statistical significance (i.e., $p < .05$).

Overall, the findings from this study were consistent with several previous studies investigating physical stamina (Muraven et al., 1998; Muraven & Shmeuli, 2006; Vohs et al., 2007) and what was originally hypothesized in terms of a cognitively-depleting self-regulatory task imparting debilitating aftereffects on isometric dorsiflexion performance.

However, there was no evidence that self-regulatory depletion affected muscle activation as seen previously in the study by Bray et al. (2008). In addition, trait self-control was shown to play a role as a potential effect modifier within the realm of acute self-regulatory depletion and physical performance. Despite the fact that no statistically significant differences emerged, the effect sizes yielded support for the limited strength model as well as for the predictive utility of trait self-control on physical performance. The following sections will discuss the results in more detail to provide potential explanations for the findings, and address some of the current study's strengths, limitations, implications, and future directions for related research.

*Hypothesis 1a: Self-Regulatory Strength Depletion and Its Negative Impact on Physical Performance*

It was expected that individuals who underwent a cognitive self-regulatory strength depletion manipulation would incur a greater performance decrement than individuals who did not encounter any self-regulatory depletion. The findings from the present study are consistent with what was originally hypothesized. Although this difference was not statistically significant ($p$ =.13), a small effect size of .27 (Cohen's $d$) in the predicted direction was detected when comparing the depletion and non-depletion groups in terms of physical performance. As such, it is contended that individuals who underwent a cognitive self-regulatory strength depletion in the form of a Stroop task showed a greater decline in physical performance compared to those who did not undergo depletion. Although previous studies that have examined self-regulatory depletion effects and physical performance have primarily used handgrip tasks (Bray et al., 2008;

Martijn et al., 2002), the current findings mesh well with existing research. For example, Martijn and colleagues (2002) found that physical stamina on a handgrip task was negatively influenced by engaging in a self-regulatory depletion manipulation, such that participants who suppressed their emotions while watching an emotionally-engaging video prior to the handgrip task incurred a greater performance decrement when compared to their non-depleted counterparts. When examining the time-to-failure difference between the depletion and non-depletion groups, a small effect size of .35 was detected, which is comparable to the present study's findings. In a recent study by Muraven & Shmueli (2006), similar findings were echoed, such that individuals who encountered a self-regulatory depletion manipulation did not persist as long on a handgrip task when compared to when they encountered no depletion. Although that study did not examine time-to-failure prior to the manipulation, a very small effect size of .05 was detected between the two conditions subsequent to the self-regulatory depletion manipulation. Lastly, in a study by Bray and colleagues (2008), a small effect size of .24 was computed for physical performance on a handgrip task subsequent to a self-regulatory manipulation comparing depleted and non-depleted groups. No differences in physical performance prior to the manipulation were detected between the depletion and non-depletion groups, suggesting that individuals who underwent the cognitive self-regulatory depletion incurred a greater performance decline than those who did not encounter the depletion.

As noted earlier, the limited strength model describes self-regulation as a limited, consumable, and renewable internal resource that is depleted when people attempt to control their emotions, thoughts, or behaviours (Muraven & Baumeister, 2000). The current study's findings speak to the underlying assumptions of the limited strength model, specifically that those individuals who experienced self-regulatory depletion in the form of a Stroop task showed a decline in their physical performance of an isometric endurance task compared to those who performed a simple reading task (i.e. no depletion). These findings are in line with previous research that has examined, and subsequently provided support for, the limited strength model of self-regulation (Baumeister, Muraven, & Tice, 2000; Muraven, Collins & Nienhaus 2002).

The lack of significant ($p < .05$) findings in the current study are due in part to low statistical power, associated with the small sample size. However, the relatively small effects may also be interpreted with several alternative explanations in mind. One factor potentially contributing to the small differences in performance seen in the current study may have been the novelty of the endurance task itself. In line with Bray and colleagues' (2008) recommendations to isolate activities involving a single muscle in future studies, ankle dorsiflexion was seen as a viable option. However, the task itself is one that may be rarely performed in everyday settings. Certainly, few activities of daily living involve purposeful sustained dorsiflexion contractions. In contrast, a handgrip squeeze, which has been the mainstay performance variable in previous studies, is performed regularly by anyone who carries a briefcase or shopping bag. Thus the participant's level of familiarity with the task was probably limited. Each participant was required to sit in a chair with their leg strapped into a device that securely held their foot in position. Measures were taken to make sure that the participants' feet and legs were secured comfortably. Adjustments were made to alleviate any discomfort they may have had after their first familiarization trial. Despite this however, general feedback from the participants indicated that pain/discomfort in the foot and leg was present at the end of the endurance trials. Thus, the novelty associated with flexing one's ankle to generate a particular force throughout the trial in combination with the discomfort and pain in the leg and foot may have prevented the participants to progress to muscle failure, regardless of being depleted. In theory, the tibialis anterior, being the primary muscle responsible for ankle dorsiflexion, was a good muscle to isolate, however the task itself requires future research in terms of a possible learning curve associated with more novel endurance tasks. One way to deal with this issue would be to expose participants to the task in one or more acclimations sessions to help familiarize them with the task.

Overall, the findings from the present study are in line with previous research within the self-regulatory and physical performance domain in terms of effect size(s) detected and the results provide limited support for the limited strength model of self-regulation.

*Hypothesis 1b: Self-Regulatory Strength Depletion Effects on Muscle Activity*

In concert with the performance differences between the non-depleted and depleted conditions, and in line with Bray and colleagues (2008), it was initially hypothesized that differences in muscle activation would emerge. Specifically, higher levels of EMG in the tibialis anterior were expected during the post-manipulation trials for the participants who engaged in the self-regulatory strength depletion when compared to the non-depletion group. Contrary to the hypothesis, the findings from the current study did not support a condition x time interaction ($p$ =.50), such that there were no differences in EMG levels between the depletion and non-depletion condition over time. In related research that has examined muscle activation while engaging in physical tasks, it has been found that there is greater activity occurring at the level of the muscle when physical tasks are performed simultaneously with mental loading tasks than when performed alone (Au & Keir, 2007; MacDonell & Keir, 2005). The only other study that has examined self-regulatory depletion effects on physical performance at the using EMG was conducted by Bray and colleagues (2008). They found that there was a difference in muscle activation ($p$<.05) between the depletion and non-depletion groups subsequent to a self-regulatory manipulation. Specifically, individuals who performed a Stroop task prior to engaging in a handgrip task not only experienced greater motor recruitment throughout the trial, but also at baseline, when compared to their non-depleted counterparts. Contrary to what has been concluded in previous literature, the findings of the current study are not in line with previous research within the general literature that has examined mental loading tasks and physical performance nor in the more specific and related research within the self-regulatory and physical performance domain. As such, the effects of self-regulatory depletion on muscle activity during sustained contractions require further research to examine the underlying mechanisms within this domain.

*Hypothesis 2: Trait Self-Control as an Effect Modifier*

Evidence suggests that individuals who report higher levels of trait self-control encounter greater success in a variety of aspects of their lives, as noted earlier. In addition, trait self-control has been used to predict performance in a variety of cognitive, emotional and behavioural domains (Galliot et al., 2006; Schmeichel & Zell, 2007). Thus, in the current study it was hypothesized that individuals who reported higher levels of trait self-control would show a smaller performance decline compared to individuals who reported lower levels of trait self-control for the depletion condition only. This was one of the first studies to examine trait self-control as an effect modifier within the self-regulation depletion and physical performance domain. Although the relevant findings from the current study do not provide statistically significant evidence in support of the initial hypothesis, they do provide insight into the relative utility of trait self-control for predicting physical performance.

The effect size detected in the current study between the "lower" and "higher" self-regulators for physical performance was small at .32 (Cohen's *d*). Nonetheless, it was in the predicted direction and is in line with previous studies that have examined the predictive utility of trait self-control in other behavioural domains. For example, in a recent study, Clayton, Bray and Martin Ginis (2008) examined trait self-control as an effect modifier of physical performance. They found that trait self-control was positively correlated with physical performance of a handgrip task ($r = .44, p < .05$), such that individuals who reported higher levels of trait self-control showed resistance to acute depletion effects on their physical performance. In addition, Schmeichel and Zell (2007) found that individuals who reported higher levels of trait self-control were better able to resist blinking their eyes and tolerate pain for a longer period of time (e.g., persistence at a cold pressor test) when compared to those lower in trait self-control.

The findings of the current study are in line with previous related research, and may also be interpreted in terms of fatigue-related differences between higher and lower trait self-regulators. Exploratory data were obtained at the end of the post-manipulation muscular endurance trial reflecting participants' perceived energy levels. Interestingly, the "lower" and "higher" trait self-regulators showed differences in terms of the extent to which they reported having "no more energy" prior to quitting the trial, $F(1,19) = 5.34, p = .03$. This finding indicates that the "lower" trait self-regulators perceived the endurance as more energy-consuming subsequent to the cognitive self-regulatory depletion task and can be interpreted in terms of central fatigue (cf. Davis, 1995; Enoka & Stuart, 1992). That is, "lower" trait self-regulators may have different limits or tolerances to central fatigue than "higher" trait self-regulators. While integrative research coupling central fatigue and self-regulatory depletion effects has been initiated (Bray et al., 2008), future consideration should be given to individual differences in fatigability and trait self-regulation.

*Why the carryover effect?*

One of the major issues arising in this study was the presence of a differential carryover effect showing an interaction between the ordering of the depletion exposure conditions over time. In attempts to decompose the carry-over effect, it was discovered that participants who engaged in the depletion-first condition at Time 1 experienced a 20 second decline in performance on their pre-manipulation endurance task from Time 1 to Time 2 ($t = 2.54, p = .02$), whereas the non-depletion-first condition at Time 1 showed a decrease of only 6 seconds in their pre-manipulation endurance scores from Time 1 to Time 2 ($t = -1.43, p = .17$).

This was one of the first studies to examine the effects of self-regulatory depletion on physical performance using a within-subjects design. From a methodological standpoint, it made sense to follow a within-subjects design to increase statistical power and reduce the variance associated with individual differences. However, one of the disadvantages with this particular design is the risk of a carryover effect. At the study design stage, a carryover effect from Time 1 to Time 2 was considered, thus a standard rest time of two days separated the two testing sessions was implemented. In previous studies that have examined muscle fatigue and recovery, the amount of rest between trials varies considerably, but typically ranges between 2 and 48 hours (Kroon & Naeije, 1991; Linnamo, Hakkinea, & Komi, 1998).

A within-subjects design had only been used in one previous study within this area of research, however Muraven and Shmueli (2006) had participants perform an isometric endurance task twice in the same testing session following both a depletion and control task. Therefore, muscle fatigue was confounded with the self-regulatory depletion effect. Also, they did not specify the amount of rest (if any) that was allowed for participants between the two testing conditions. Taking into consideration the literature on muscle fatigue recovery, two days seemed to be an adequate amount of time to allow the muscle to replenish. Also, since all participants had two days of rest between Time 1 and Time 2, fatiguing effects due to the muscular endurance task alone are unlikely to have caused the differential carryover effect. However, despite taking the effect of muscular fatigue recovery into consideration, compensating for additional effects of cognitive self-regulatory depletion were not weighed in. Perhaps the combination of the cognitive self-regulatory depletion and physical endurance task may have had more of a centrally fatiguing impact than was originally anticipated, in terms of long-lasting aftereffects.

Of particular interest when interpreting this finding is a phenomenon referred to as low-frequency fatigue. Low-frequency fatigue is characterized by a loss of force-generating capability that is long-lasting, taking hours or days to subside. First noted by Edwards and colleagues (1977b), low-frequency fatigue can be induced via voluntary contractions or low-frequency electrical stimulation (Chin, Belnave, & Allen, 1997) of the muscle. Since there were no differences in maximal force-generating capability from Time 1 to Time 2, we can assume that there was no low-frequency fatigue present. However, Nybo (2003) has illustrated that following prolonged muscular endurance activity in higher and lower central fatigue conditions, brief maximal force production is unaffected, but sustained performance declines more rapidly with greater fatigue. Future research accounting for low-frequency fatigue effects from a central fatigue perspective may shed light on the differential carry-over effects shown in this study.

Another potential explanation for the differential carry-over effect is acute aversive associative learning. Aversive associative conditioning occurs within, and is part of, associative learning, whereby a conditioned stimulus (CS) is paired with an aversive event referred to as the unconditioned stimulus (US), and subsequently a conditioned response (CR) manifests upon presentation of the CS (Pavlov, 1927). The CR can manifest in a number of ways, from affective reactions, physiological changes, and avoidance. For example, when an individual encounters a particular event that elicits feelings of "unpleasantness" they will avoid the situation in the future so as to not experience the displeasure they associate with the task (DeHouwer, Thomas, & Baeyens, 2001). Thus, from an associative learning perspective, the participants who underwent the depletion manipulation at their first testing session and experienced both the combination of the Stroop task and physical endurance task may have had a more aversive experience than those in the non-depletion condition. As a consequence, they may have unconsciously anticipated a similarly aversive experience at their second testing session, which affected their pre-manipulation performance.

Although the differential carry-over effect was problematic in terms of data analysis and interpretation, this effect raises several issues in terms of methodological considerations as well as potential research avenues. In particular, the effects of self-regulatory depletion on physical stamina may have more than an acute effect which raises new questions about acute as well as lasting effects of self-regulatory depletion on physical stamina. Clearly, future research is needed to evaluate dose and response issues regarding self-regulatory depletion and should be considerate of the possibility of carryover effects associated with both physical and cognitive depletion.

*Study Limitations*

Although the findings of the present study are encouraging, it is necessary to acknowledge its limitations. First, the sample size employed in the study was relatively small. Due to the carryover effect that emerged between the two orders of exposure,the number of observations used in the overall analyses was halved from the original data set and a between-subject analysis was performed. The original rationale for implementing a within-subjects design was based on the high degree of variability associated with physical endurance tasks and this was the case in the current study. The low statistical power associated with the small sample size in the current study limits our confidence in interpreting the overall results. Although the effect size of .27 detected for performance scores between the depletion and non-depletion groups is comparable with previous research, the confidence in the overall findings are limited due to the low statistical power (i.e., small sample size).

A second consideration of the study's findings is that they are limited to the acute manipulation of self-regulatory tasks performed in a laboratory setting. The Stroop task has been used in prior studies (Au & Keir, 2006; Bray et al., 2008) examining its deleterious effects on tests of muscular strength and endurance, and is an adequate cognitive self-regulatory depletion manipulation tool. However, the Stroop task that the participants engaged in was intense and brief. The extent to which depletion effects elicited by the Stroop task compare with those of typical everyday tasks requiring self-regulation is not known. As well, the criterion task performed in the current study, an isometric contraction of the ankle dorsiflexors, is a rare task for anyone to perform. Although rationale was provided for the physical endurance task used in the current study, its real-life applicability to other forms of physical tests of endurance may be quite limited. For example, an individual's performance on the in laboratory ankle dorsiflexion task may or may not predict one's performance level while engaging in exercise. In short, the current study's use of the acute manipulation and subsequent test of muscular endurance was adequate for our purpose, but future research might examine more complex, multi-tasking physical behaviours and cognitive self-regulatory depletion.

*Study Strengths*

Balanced against the abovementioned limitations, the current study also had a number of strengths. Although a problematic differential carry-over effect was discovered, the results add to a growing body of research showing that cognitive depletion imparts deleterious effects on physical performance. Additional research is warranted in order to uncover the mechanisms underlying the carryover effect in and of itself within the self-regulatory depletion and physical performance domain.

Also, this study was among the first to provide evidence that trait self-control is related to success at behavioural self-control challenges. As mentioned earlier, there is a high degree of variance associated with the performance scores obtained in physical endurance tasks. Testing this potential effect modifier provided insight into one underlying factor responsible for the high degree of variance associated with self-regulatory depletion effects in the physical task domain.

*Implications and Future Directions from the Current Study*

As mentioned earlier, trait self-control has been shown to be very useful in predicting behavioural outcomes, and higher levels of trait self-control have been associated with more positive behavioural outcomes (Schmeichel & Zell, 2007; Tangney et al., 2004). The results from this study indicate that there was a difference in physical performance while performing a muscular endurance task after encountering a self-regulatory depletion manipulation between people with high and low levels of trait self-control. In terms of the applicability of these findings beyond the laboratory, it may be important to consider one's ability to self-regulate, or their trait capacity for self-control, when prescribing exercise routines. For example, it may be beneficial for a beginner exerciser to arrange exercise training sessions at times when the individual has not encountered a great deal of self-regulatory depletion, like exercising in the early morning rather than after a stressful or emotionally draining day at the office.

Turning from the exercise domain to the workplace, identifying individual levels of trait self-control might prove beneficial in avoiding workplace injury. As noted, there is a difference in levels of self-regulatory physical performance between those who report "lower" and "higher" levels of trait self-control. This distinction in performance levels might negatively affect some employees' abilities to multi-task on the job. It has been found that the interfering effects of multitasking (e.g., performing muscle contractions and mental processing) increase muscle activity (Au & Keir, 2006). Increased muscle activity, even in small amounts, can lead to overall muscle fatigue, and eventually to musculo-skeletal injuries. Future research examining trait self-control and self-regulatory demands of work in predicting workplace injuries is warranted.

The present study attempted to advance current research within the self-regulatory and physical performance domain as well as provide further support for the limited strength model. While the study's findings are in line with previous research and original hypotheses, the unpredictable outcome of the differential carry-over effect was disappointing. As outlined earlier, there are a few potential reasons for this finding which should be addressed in the future. One important consideration is to allow sufficient time for fatigue carry-over effects to disappear when examining repeated self-regulatory depletion conditions. Along these lines, it is also important to examine the underlying mechanisms for carry-over effects that may occur for theoretically interesting reasons (i.e., as an interaction of cognitive and physiological fatigue).

*Conclusion*

The findings from this study provide support for the limited strength model (Muraven & et al., 1998; 2000) which describes self-regulation as a limited, consumable and internal resource that can be depleted. The findings also provided support for trait self-control as an individual difference factor affecting self-regulatory depletion effects in the physical performance domain. Future research that addresses the underlying mechanisms of underlying self-regulatory depletion effects such as central fatigue is needed.

References

Alnaqeeb, M. A., & Goldspink, G. (1987). Changes in fibre type, number and diameter in developing and ageing skeletal muscle. *Journal of Anatomy, 153*, 31-45.

Au, P. & Keir, P. J. (2007). Interfering effects of multitasking on muscle activity in the upper extremity. *Journal of Electromyography and Kinesiology, 17*, 578-586.

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology, 74,* 1252-1265.

Baumeister, R. F., Galliot, M., DeWall, C. N., & Oaten, M. (2006). Self-regulation and personality: How interventions increase self-regulatory success, and how depletion moderates the effects of traits on behavior. *Journal of Personality, 74*, 1773-1801.

Baumeister, R. F & Heatherton, T. F. (1996). Self-regulation failure: An overview. *Psychological Inquiry, 7*, 1-15.

Baumeister, R. F., Heatherton, T. F., & Tice, D. M. (1994). *Losing control: How and why people fail at self-regulation.* San Diego, CA: Academic Press.

Baumeister, R. F., Muraven, M., & Tice, D. M. (2000). Ego depletion: A resource model of volition, self-regulation, and controlled processing. *Social Cognition, 18,* 130-150.

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The Strength Model of Self-Control. *Current Directions in Psychological Science, 16*, 351-355.

Bigland-Ritchie, B., Furbush, F., & Woods, J. J. (1986). Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors. *Journal of Applied Physiology, 61,* 421-429.

Booth, F. W. & Lees, S.J. (2007). Fundamental questions about genes, inactivity, and chronic diseases. *Physiological Genomics, 28,* 146-157.

Borg, G. (1998). *Borg's perceived exertion pain scales.* Champaign, IL: Human Kinetics.

Bouchard, C. (2007). Genetics and health benefits associated with physical activity. *American Journal of Human Biology, 19,* 294-294.

Bray, S. R., Martin Ginis, K. A., Hicks, A. L. & Woodgate, J. (2008). Effects of self-regulatory depletion on muscular performance and EMG activation. *Psychophysiology*, 45, 337-343.

Canadian Fitness and Lifestyle Research Institute. (2005). Canada Physical Activity Statistics. Retrieved on Tuesday, November, 20, 2007, from http://www.cflri.ca/eng/provincial_data/pam2005/canada.php.

Carver, C. S., & Sheier, M. F. (1982). *Attention and self-regulation: A control theory approach to human behavior.* New York: Springer-Verlag.

Carver, C. S., & Sheier, M. F. (1998). *On the self-regulation of behavior.* New York: Cambridge University Press.

Chin, E. R., Balnave, C. D., & Allen, D. G. (1997). Role of intracellular calcium and metabolites in low-frequency fatigue of mouse skeletal muscle. *American Journal of Physiology, 272,* C550-C559.

Clayton, C. S., Bray, S. R., & Martin Ginis, K. A. (2008). Self-regulatory depletion and physical performance: An examination of depletion effects and trait self-control as an effect modifier. *Journal of Sport and Exercise Psychology, 30,* S159.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112,* 155-159.

Davis, M. (1995). Carbohydrates, branched-chain amino acids, and endurance: The central fatigue hypothesis. *International Journal of Sport Nutrition, 5,* S29-S38.

DeHouwer, J., Thomas, S., & Baeyen, F. (2001). Associative learning of likes and dislikes: A review of 25 years of research on human evaluative conditioning. *Psychological Bulletin, 127,* 853-869.

Dishman, R. K. (1988). Determinants of physical activity and exercise for persons 65 years of age or older. *Academy Papers, 22,* 140-162.

Edwards, R. H., Hill, D. K., Jones, D. A., & Mertona, P. A. (1977). Fatigue of long duration in human skeletal muscle after exercise. *Journal of Physiology, 3,* 769-778.

Enoka, R. M., & Stuart, D. G. (1992). Neurobiology of muscle fatigue. *Journal of Applied Physiology, 72,* 1631-1648.

Finkel, E., & Campbell, W.K. (2000). *Ego depletion and accommodation in romantic relationships.* Poster presented at the Society for Personality and Social Psychology, Nashville, TN.

Gandevia, S.C. (1992). Some central and peripheral factors affecting human motoneuronal output in neuromuscular fatigue. *Sports Medicine, 13*, 93–98.

Gandevia, S.C. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiological Reviews, 81,* 1725–1789.

Galliot, M. T. & Baumeister, R. F. (2007). Self-regulation and sexual restraint: Disposionally and temporarily poor self-regulatory abilities contribute to failures at restraining sexual behaviour. *Personality and Social Psychology Bulletin, 33,* 173-186.

Galliot, M. T., Baumeister, R. F., DeWall, N. C., Maner, E., Plant, A., Tice, D. M., Brewer, L. E., & Schmeichel, B. J. (2007). Self control relies on glucose as a limited energy source: Willpower is more than a metaphor. *Journal of Personality and Social Psychology, 92*, 325-336.

Galliot, M. T., Schmeichel, R. T., & Baumeister, R. F. (2006). Self-regulatory processes defend against the threat of death: Effects of self-control depletion and trait self-control on thoughts and fears of dying . *Journal of Personality and Social Psychology, 91*, 41-62.

Gilbert, D. T., Krull, D. S., & Pelham, B. W. (1988). Of thoughts unspoken: Social inference and the self-regulation of behavior. *Journal of Personality and Social Psychology, 55,* 685-694.

Gottfredson, M. R. & hirschi, T. (1990). *A general theory of crime.* Palo Alto, CA: Stanford University Press.

Graham, R., Kremer, J., Wheeler, G. (2008). Physical exercise and psychological well-being among people with chronic illness and disability: A grounded approach. *Journal of Health Psychology, 13,* 447-458.

Grizzle, J. E. (1965). The two-period change-over design and its use in clinical trials. *Biometrics, 21*, 467-480.

Haggar, M. S., Chatzisarantis, N. L. D., & Biddle, S. J. H. (2002). The influence of autonomous and controlling motives on physical activity intentions within the Theory of Planned Behavior. *British Psychological Journal, 7*, 283-297.

Hallahan, M. & Rosenthal, R. (1996). Statistical power: Concepts, procedures, and applications. *Behaviour Research and Therapy, 34*, 489-499.

Health Canada. (1998). *Canada's Physical Activity Guide to Health Active Living.*

Retrieved on Thursday, October 18, 2007 http://www.phac-aspc.gc.ca/pau-uap/paguide/

Health Canada. (2002). Physical Activity Readiness Questionnaire. Retrieved on Monday, September, 8, 2008 http://www.phac-aspc.gc.ca/pau-uap/paguide/questionnaire.html

Heatherton, T. F., & Baumeister, R. F. (1996). Self-regulation failure: Past, present, and future. *Psychological Inquiry, 7,* 90-98.

Jones, B. A. & Kenward, M. G. (2003). *Design and analysis of cross-over trials.* Boca Raton, CA: Chapman & Hall.

Kent-Braun, J. A. (1999). Central and peripheral contributions to muscle fatigue in humans during sustained maximal effort. *European Journal of Applied Physiology, 80,* 57-63.

Kroon, G. W., & Naeije, M. (1991). Recovery of the human biceps electromyogram after heavy eccentric, concentric or isometric exercise. *European Journal of Applied Physiology, 63,* 444-448.

Linnamo, V., Hakknea, K., & Komi, P. V. (1998). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology, 77,* 176-181.

MacDonell, C. W., & Keir, P. J. (2005). Interfering effects of the task demands of grip force and mental processing on isometric shoulder strength and muscle activity. *Ergonomics, 48,* 1749-1769.

Martijn, C., Tenbuilt, P., Merckelbach, H., Dreezens, E., & deVries, N. K. (2002). Getting a grip on ourselves: Challenging Expectancies about loss of energy after self-control. *Social Cognition, 20,* 441-460.

Mayer, J. D., & Gaschke, Y. N. (1988). The experience and meta-experience of mood. *Journal of Personality and Social Psychology, 55,* 102-111.

Mayer, J. D. (2007, November 11). *Measuring mood, meta-mood, and empathy: Scoring instructions for the BMIS.* Retrieved April 24, 2008 http://www.unh.edu/emotional_intelligence/index.html

McAuley, E. (1993). Self-efficacy and the maintenance of exercise participation in older adults. *Journal of Behavioral Medicine, 16,* 103-112.

McKenzie, D. K., Bigland-Ritchie, B., Gorman, R. B., & Gandevia, S. C. (1992). Central and peripheral fatigue of human diaphragm and limb muscles assessed by twitch interpolation. *Journal of Physiology, 454,* 643-656.

Mischel, W. (1996). From good intentions to willpower. In P. M. Gollwitzer & J. A. Bargh (Eds.) *The psychology of action: Linking cognition and motivation to behavior* (pp. 197-218). New York: Guilford Press.

Muraven, M. & Baumiester, R. F. (2000). Self regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin, 126*, 247-259.

Muraven, M., Collins, R. L., & Nienhaus, K. (2002). Self-control and alcohol restraint: An intial application of the self-control strength model. *Psychology of Addictive Behaviors, 16,* 113-120.

Muraven, M. & Shmueli, D. (2006). The self-control of fighting the temptation to drink. *Psychology of Addictive Behaviors, 20,* 154-160.

Muraven, M. & Slessevera, E. (2003). Mechanisms of self-control failure: Motivation and limited resources. *Personality and Social Psychology Bulletin, 29*, 894-906.

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self control as a limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology, 74,* 774-789.

Nybo, L., Moller, K., Pedersen, B. K., Nielsen, B., & Secher, N. H. (2003). Association between fatigue and failure to preserve cerebral energy turnover during prolonged exercise. *Acta Physiologica Scandinavica, 179,* 67-74.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116,* 220-244.

Pavlov, I.I. (1927) *Conditioned Reflexes*, Translated by G.V. Anrep, London: Oxford University Press.

Reid, R. D. (2006). Determinants of physical activity after hospitalization for coronary artery disease: the Tracking Exercise After Cardiac Hospitalization (TEACH) Study. *European Journal of Cardiovascular Prevention and Rehabilitation, 13,* 529 – 537.

Ren, J. M., Semenkovich, C. F., Gulve, E. A., Gao, J. & Holloszy, J. O. (1994). Exercise induces rapid increase in GLUT4 expression, glucose transport capacity, and insulin-stimulated glycogen storage in muscle. *Journal of Biological Chemistry, 269,* 14396 – 14401.

Sallis, J. F., & Owen, N. (1999). *Physical activity and behavioral medicine.* London, UK: Sage Publications.

Schmeichel, B. J., & Baumeister, R. F. (2004). Self-regulatory strength. In R. F. Baumeister & K. D. Vohs (Eds.) *Handbook of self-regulation: Research, theory and applications* (pp.84-98). New York: Guilford.

Schmeichel, B. J. & Zell, A. (2007). Trait self-control predicts performance on behavioral tests of self-control. *Journal of Personality, 75*, 743-755.

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality, 72,* 271-322.

Tice, D. M., & Baumeister, R. F. (1997). Longitudinal study of procrastination, performance, stress, and health: The costs and benefits of dawdling. *Psychological Science, 8,* 454-458.

Tice, D. M., Baumeister, R. F., Shmueli, D., & Muraven, M. (2007). Restoring the self: Positive affect helps improve self-regulation following ego depletion. *Journal of Experimental Social Psychology, 43,* 379-384.

Van Schaik, C. S., Hicks, A. L., McCartney, N. (1994). An evaluation of the length-tension relationship in elderly human ankle dorsiflexors. *Journal of Gerontology: Medical Sciences, 49,* B121-B127.

Vander, A., Sherman, J., & Luciano, D. (2001). *Human physiology: The mechanisms of body function.* New York, NY: McGraw-Hill.

Vohs, K. D. (2006). Self-regulatory recourses power the reflective system: Evidence from five domains. *Journal of Consumer Psychology, 16*, 215-221.

Vohs, K. D., Baumesiter, R. F., Schmeichel, B. J., Twenge, J. M., Nelson, N. M., & Tice, D. M. (2008). Making choices impairs subsequent self-control: A limited-resource account of decision making, self-regulation, and active initiative. *Journal of Personality and Social Psychology, 94,* 883-893.

Vohs. K. D., & Faber, R. J. (2007). Spent resources: Self-regulatory resource availability affects impulse buying. *Journal of Consumer Research, 33*, 537-547.

Vohs, K. D. & Heatherton, T.F. (2000). Self-regulatory failure: A resource depletion approach. *Psychological Science, 11*, 249-254.

Wallace, H. M. & Baumeister, R. F. (2002). The effects of success versus failure feedback on further self-control. *Self and Identity, 1*, 35-42.

Wang, Y., Zhang, C., Yu, R. T., Cho, H. K., Nelson, M. C., Bayuga-Ocampo, C. R., et al. (2004). Regulation of muscle fiber type and running endurance by PPAR δ. PLoS Biology, 2, e294.

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal, 174*, 801-809.

Winter, D. A. (2005). Biomechanics and motor control of human movement (3rd ed). New Jersey: John Wiley & Sons, Inc.

# Appendix A

## Participant Screening Questionnaire

## PARTICIPANT SCREENING QUESTIONNAIRE

Date: ____________________________
Age: __________

Do you have a pacemaker (and/or similar device)? Yes No
Do you have diabetes? Yes No
Do you have any neuromuscular problems? Yes No
If yes, please describe:

____________________________________________________________

Over the past 6 months, how many times **on average** have you done the following kinds of exercise for MORE THAN 30 minutes during your **free time** each week?

**Times per week**

**STRENUOUS EXERCISE (your heart beats rapidly):**

_______________

(e.g. running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling, skating)

**MODERATE EXERCISE (not exhausting):**

_______________

(e.g. fast walking, weight-training, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, dancing)

**MILD EXERCISE (minimal effort):**

_______________

(e.g. yoga, archery, fishing, bowling, horseshoes, golf, snow-mobiling, easy walking)

**How many days per week do you consistently exercise?** _______________

**Are you colour blind?** **Yes** **No**

**Additional Questions:**

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by your doctor? Yes No
2. Do you feel pain in your chest when you do physical activity? Yes
   No

3. In the past month, have you had chest pain when you are not doing physical activity? Yes
   No

4. Do you lose balance because of dizziness or do you lose consciousness? Yes
   No

5. Do you have a bone or joint problem (for example back, knee or hip) that could be made worse by a change in your physical activity? Yes No

6. Is your doctor currently prescribing drugs (for example water pills) for your blood pressure or heart condition? Yes No

7. Do you know of any other reason why you should not do physical activity? Yes No

If yes, please explain.

---

**Researcher Use Only:**

| | |
|---|---|
| **APPOINTMENT DATE:** | |
| **APPOINTMENT TIME:** | |
| **Participant's email address:** | |

# Appendix B

## Consent Form

**CONSENT TO PARTICIPATE IN RESEARCH: BASELINE LAB-BASED STUDY**

*Self-regulation and Ankle Dorsiflexion Study*

You are being invited to participate in a research study carried out by Courtney Clayton, Drs. Steven Bray, and Audrey Hicks (Dept. of Kinesiology, McMaster University). The study is sponsored by the Social Sciences and Humanities Research Council. If you have any questions or concerns about the study, please feel free to contact Dr. Steven Bray at (905) 525-9140 ext. 26472.

**RATIONALE**

This study is designed to provide information regarding individual performance on a physical endurance task.

**PURPOSE OF THE STUDY**

The primary purpose of the study is to examine the difference across two trials of an isometric physical endurance task.

**PROCEDURE**

The study will take approximately 45 minutes to complete. It involves performing two separate physical tasks of ankle flexion, completing a reading task, and filling out questionnaires about your personality and mood.

**POTENTIAL RISKS AND DISCOMFORTS**

There are no known risks associated with taking part in this study. You might find that the device which holds your foot and leg in place may be slightly uncomfortable. If you experience any pain while performing the physical task you should tell the researcher immediately.

**POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY**

There are no direct benefits to you from taking part in this study. The results from this study will help the scientific community better understand the effects of self-regulatory cognitive tasks on physical performance.

**PAYMENT FOR PARTICIPATION**

You will be paid $20 cash for completing this study. If you drop out before completing the study, your compensation will be prorated. All compensation will be given at the end of the lab session.

**CONNFIDENTIALITY**

Any information that is obtained during this study can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. The questionnaires are completely private and will be kept in a locked filing cabinet in The Health and Exercise Psychology Laboratory for a period of five years. Only the researchers and research assistants will have access to this information. Your identity will never be revealed in any reports of the study.

**PARTICIPATION AND WITHDRAWAL**

You can decide whether to take part in the study or not. If you volunteer for this study you may withdraw at any time. You may also refuse to answer any questions you don't want to answer while remaining in the study.

**RIGHTS OF RESEARCH PARTICIPANTS**

You may withdraw your consent and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because you are participating in this research study. This study has been reviewed and received ethics approval through the McMaster Research Ethics Board (MREB). If you have any questions regarding your rights as a research participant, contact the Office of Research Services, McMaster University (Phone: (905)329-2747).

**SIGNATURE OF RESEARCH PARTICIPANT**

I understand the information provided for the ***Self-regulation and Ankle Dorsiflexion*** study of as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I will receive a signed copy of this form.

______________________________________

Name of Participant

______________________________________ ____________________

Signature of Participant Date

Consent for administered and explained in person by:

______________________________________
Name and Title

______________________________________ ____________________
Signature Date

SIGNATURE OF INVESTIGATOR
In my judgement, the participant is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

______________________________________ ____________________
Signature of Investigator Date

# Appendix C

## RPE Scales

Appendix C1:

## Rating your Physical Performance – Endurance Task

**Below is a scale, from 1 to 10, that provides a rating of how much effort you felt you exerted while performing the endurance task.**

| RPE Numeric Value | Definition |
|---|---|
| 1 | **Very Weak Effort**<br>When I performed the task, I put forward little to no effort at all. |
| 2 | |
| 3 | **Little Effort**<br>I put forward some effort, but did not exert myself. |
| 4 | |
| 5 | **Moderate Effort**<br>I tried pretty hard to go for a long time, but I think I could have gone longer. |
| 6 | |
| 7 | **Very Strong Effort**<br>I did push myself to go for as long as I could. |
| 8 | |
| 9 | |
| 10 | **"All-out" Effort**<br>There was no way I could have performed the task for any longer. I put everything I had to go to the very end. |

Appendix C2:
## Rating your Physical Performance - MVC

**Below is a scale, from 1 to 10, that provides a rating of how much effort you felt you exerted while performing the endurance task.**

| RPE Numeric Value | Definition |
|---|---|
| 1 | **Very Weak Effort**<br>When I performed the task, I put forward little to no effort at all. |
| 2 | |
| 3 | **Little Effort**<br>I put forward some effort, but did not exert myself. |
| 4 | |
| 5 | **Moderate Effort**<br>I tried pretty hard to pull my foot up, but I think I could have done better. |
| 6 | |
| 7 | **Very Strong Effort**<br>I did push myself to pull my foot with a great deal of strength. |
| 8 | |
| 9 | |
| 10 | **"All-out" Effort**<br>There was no way I could have performed the task with any more force. I pulled my foot as hard as I possibly could. |

# Appendix D

## Questionnaire Package

**To begin, we are interested in getting to know some basic information about you. Please complete the following questions.**

**Age:** _______
**Height:** ____ft. ____inches **Weight:** _______lbs
**Gender (please circle):** Male Female
**Marital Status:**
Single ____ Married ____ Divorced ____ Common-law ____ Widowed ____
**Ethnicity:** Caucasion ____ Asian _____African American _____ Other _____
**At McMaster, you are a:** Undergraduate Student _____
Graduate Student _____
Faculty: _____
Staff: _____
Other: _____
If you are a student, what year of study are you currently in? ______
What faculty? ______________________________
What program? ______________________________

These items are statements about your reactions to the word task you just completed. Please read each statement and circle your response using the scales below.

1. How much mental effort did you exert while doing the word task?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Little Effort** | | | | | | **Extreme Effort** |

2. How tired do you feel after doing the word task?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Not at all** | | | | | | **Extremely** |

3. How frustrated do you feel after doing the word task?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Not at all** | | | | | | **Extremely** |

4. How pleasant did you find doing the word task?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Not at all** | | | | | | **Extremely** |

The next items are statements about your mood. Please circle the response on the scale below that indicates how well each adjective describes your present mood.

1. LIVELY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

2. PEPPY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

3. ACTIVE:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

4. HAPPY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

5. LOVING:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do** |

**Feel**

6. CARING:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

7. DROWSY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

8. TIRED:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

9. NERVOUS:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

10. CALM:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

11. GLOOMY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

12. FED UP:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

13. SAD

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

14. JITTERY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

15. GROUCHY:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

16. CONTENT:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DO NOT feel** | | | | | | **Definitely Do Feel** |

**Please answer the following items as they apply to you. There are no right or wrong answers. Please choose a number (1 - 5) that best represents what you believe to be true about yourself for each question. Use the following scale to refer to how much each question is true about you.**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| **Not at all like me** | | **Sometimes like me** | | **Very much like me** |

1. I have a hard time breaking bad habits. ____
2. I am lazy. ____
3. I say inappropriate things. ____
4. I never allow myself to lose control. ____
5. I do certain things that are bad for me. ____
6. People can count on me to keep on schedule. ____
7. Getting up in the morning is hard for me. ____
8. I have trouble saying no. ____
9. I change my mind often. ____
10. I blurt out whatever is on my mind. ____
11. People would say describe me as impulsive. ____
12. I refuse things that are bad for me. ____
13. I spend too much money. ____
14. I keep everything neat. ____
15. I am self-indulgent at times. ____
16. I wish I had more self-discipline. ____
17. I am good at resisting temptation. ____
18. I get carried away by my feelings. ____
19. I do many things on the spur of the moment. ____
20. I don't keep secrets very well. ____
21. People would say that I have iron self-discipline. ____
22. I have worked or studied all night at the last minute. ____
23. I am not easily discouraged. ____
24. I'd be better off if I stopped to think before acting. ____
25. I engage in healthy practices. ____
26. I eat healthy foods. ____
27. Pleasure and fun sometimes keep me from getting work done. ____
28. I have trouble concentrating. ____
29. I am able to work effectively toward long-term goals. ____
30. Sometimes I can't stop myself from doing something, even if I know it's wrong. ____
31. I often act without thinking through all the alternatives. ____
32. I lose my temper too easily. ____
33. I often interrupt people. ____
34. I sometimes drink or use drugs in excess. ____
35. I am always on time. ____
36. I am reliable. ____

**Please use the following scale to indicate the extent to which each word below describes how you feel right now, at the moment in time. Record your response on the line next to each word.**

| **0** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| Do not feel | Feel Slightly | Feel Moderately | Feel Strongly | Feel Very Strongly |

1. Calm ____
2. Refreshed ____
3. Enthusiastic ____
4. Relaxed ____
5. Energetic ____
6. Happy ____
7. Fatigued ____
8. Tired ____
9. Revived ____
10. Peaceful _____
11. Worn-out _____
12. Upbeat _____

# Appendix E

## Quit Items

1. Did you feel that you performed on the endurance trial the best you possibly could?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Not at all | | | Somewhat | | | Most Definitely |

2. Did you hold the contraction longer, shorter, or just the same as you initially thought you would?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| A lot Less | A Little Less | Same | A Little More | A Lot More |

1. Please circle the response on the scale below that indicates how well each statement describes the reason(s) why you quite the trial.

Discomfort/pain in the foot:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

Discomfort/pain in the leg:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

Was bored:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

Just felt lazy:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

No more energy:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

Thought I had done enough:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

Felt tired:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID <u>NOT</u> feel** | | | | | | **Definitely Did Feel** |

The sooner I stopped, the sooner I could leave:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID NOT feel** | | | | | | **Definitely Did Feel** |

I didn't really care:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID NOT feel** | | | | | | **Definitely Did Feel** |

I never push myself, so why now:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Definitely DID NOT feel** | | | | | | **Definitely Did Feel** |

# Appendix F

## Script Procedure

1. Introduction and informed consent:

   - When participants arrive at the lab, the RA will let the participant know what will be expected of them during the testing period
   - Verbal confirmation that participant does not have any sort of pacemaker/electrical device in their body, they are not diabetic, and have not consumed food in the last three hours
   - Once participant has read overview and information about the study, they will sign the consent.

   **"Before we get started, I just want to go over what you will be doing in this session today. The total time of the session will take approximately 45 minutes. During this time you will fill out some questionnaires, perform two separate physical bouts of ankle flexion, consume a semi-sweetened beverage, and complete a reading task. Do you have any questions?"**

2. Weight & Height

   - Weigh participant
   - Take height measurement

3. Electrode placement & task familiarization

   - Participants will sit comfortably in the chair where they will be doing their physical task. The RA will palpate the tibialis anterior and place electrodes on accordingly – belly of muscle, tendon of muscle, and lateral aspect of lower leg (ground electrode).
   - Additionally, the twitch electrodes will be placed and tested on the nerve at the lateral head of fibula and anterior aspect of patellar tendon (ground).
   - Before the participant is set up in the boot device, the researcher will confirm the electrodes are in place by twitching the nerve while palpating the TA to make sure it's contracting.
   - Once the electrodes are on correctly, the participant's leg will be fixed in machine firmly.
   - To determine an adequate twitch level, the participant will experience subsequent twitches to determine maximal twitch response. ~ output between 40 to 60 mV
   - Record max output once determined. TURN OUTPUT TO ZERO in the meantime.
   - The individual will then be asked to perform their two MVC's for 5 seconds each, separated by a 1 minute break.
   - In the middle of their MVC, the participant will experience an additional twitch

   **"So if I can get you to come and sit in this chair here, I will place these electrodes on your lower leg. These are connected to this machine and it will tell us how your muscle is working while you flex during the contraction. I am also going to place another set of electrodes that are going to stimulate the nerve that innervates the muscle. Now I am going to put your lower leg in this machine here. I want you to**

**feel snug in here, but I don't want it to be painful. The goal of this is to avoid other muscles contributing to the contraction of your ankle. Ok great."**

**"Now we are going to see if everything is working fine and get you familiar with what the action of flexing your foot feels like. If you could bring the lower part of your foot up to your knee as far as it will go. Try not to lift your leg at all, just bring your toes up towards the ceiling. How does that feel?"**

**"At this time, I am going to stimulate the nerve and you will feel your muscle contract. I am going to do this a few times to see what the appropriate stimulation level is for you. If you find this really uncomfortable, please let me know. It shouldn't hurt at all, but it will feel different. Alright, let's get started."**

**"Ok, now that you have an idea of the action, I would like you to perform a maximal contraction of ankle flexion, as hard as you can. What you are going to have to do is hold this contraction for 5 seconds. I want you to bring your lower foot up towards your leg and hold for 5 seconds. I will tell you when you begin and subsequently when you can let go of the contraction. I want you to make sure that the contraction is held as hard as possible and that you are putting as much strength into the contraction as possible. At a few seconds into the contraction, I am going to "twitch" your nerve. Please try to continue to hold the contraction until I tell you to stop. Do you have any questions?"**

- Allow 1 minute rest before second MVC trial

**"Great. Now we can do that one more time. Again, holding it for 5 seconds."**

4. Fatigue trial.
   - Allow 1 minute rest from last max MVC before fatigue trial
   - Participant will hold ankle dorsiflexion contraction at 50% of MVC until fatigued.
   - Once both MVC's are completed, participants will be asked to perform ankle dorsiflexion while in the boot to get an idea of what it feels like before they perform the initial two maximal voluntary contractions (MVC) – no longer than 30 seconds total, with a 1 minute break before actual trial is performed.
   - RA will make sure that the participant is staying at the prescribed level without encouraging them to continue, but monitoring that they are staying at the appropriate level.
   - Once the participant has fallen under prescribed value for more than 2 seconds, they will be told to stop and final time will be taken.

**"What I would like you to do now is perform the same action you just did, but at 50% force of your maximum contraction. So it won't be an "all out" contraction, but just half of what you did before. Looking at the monitor here, you will see that you should hold your contraction at (calculated value from MVC) for as long as you can. I want you to hold this contraction at the line here. Once you have**

**dropped below the line for loner than 2 seconds, the trial will be over. I don't know how long you will be able to hold it for because everyone is different."**

**"And if you can, please try to tell me when you think you are at the very end of your fatigue trial. With only a few seconds left, I am going to stimulate your nerve once again."**

5. Random Assignment:

- Participants will be randomly assigned to the experimental condition (SR depletion) or the control condition (no SR depletion).

EXPERIMENTAL CONDITION:

- Participants will perform a variation of the Stroop test
- Give participants the list of 135 words (3 sheets) that are all the names of colours (e.g., RED, GREEN, BLUE, etc.). However, the words and their ink colours will not be matched (e.g. RED might be written in blue ink and GREEN might be in yellow ink).
- The total time for this task will be 6 minutes

"Now I am going to get you to do a reading task. For this task I am going to ask you to read the ink colour of each word, unless the ink colour is red in which case you ignore the ink colour and read the actual word to me. I will be timing you while you read the words, so try to read them as quickly and accurately as you can. If you make a mistake, don't try to correct yourself, please just move one to the next word. I will tell you when to stop, however if you get to the end of the third page before I say stop, please go back to the beginning."

**"Just so I know that you understand what to do, I am going to have you read these 5 words on this practice sheet here." (hand participant sheet to read)**

**"Great. Just a reminder to read the ink colour of each word, unless it's written in red ink, in which case you read the actual word to me. And if you do get to the end and I have not told you to stop, please go back to the beginning and start over. Are you ready to begin? Ok you can start."**

- Follow through with participant and record errors on record sheet.

- Keep track of the time with stop watch and stop participant at 6mins. Write down total errors on record sheet.

CONTROL CONDITION:

- Give participants the list of the 135 words that are all names of colours (e.g., RED, YELLOW, etc.). This list of words will match their colour (e.g., RED printed in red ink and GREEN printed in green ink).

**"Now I am going to get you to do a reading task. For this task I am going to ask you to read the ink colour of each word. I will be timing you while you read the words, so try to read them as quickly and accurately as you can. If you make a mistake, don't try to correct yourself, please just move one to the next word. I will tell you when to stop, however if you get to the end of the third page before I say stop, please go back to the beginning."**

**"Just so I know that you understand what to do, I am going to have you read these 5 words on this practice sheet here." (hand participant sheet to read)**

**"Great. Again, just read the ink colour of each word out to me. If you get to the end and I have not told you to stop, please go back to the beginning and start over. Are you ready to begin? Ok you can start."**

6. Manipulation check items:
   - Participants will complete manipulation check questionnaires

7. Health Check and Demographic Information:
   - Participant will fill health and demographic information questionnaire

8. Participants will now complete some questionnaires
   - Brief Self Control Scale (36 items)
   - Brief Mood Inspection Scale

9. Post-manipulation physical task
   - Participants will be asked to perform ankle dorsiflexion (10 seconds) while looking at the screen to get an idea of what it feels like once again before they perform the initial two MVC's.
   - Participants will perform two MVC's of ankle dorsiflexion for 5 seconds
   - RA will calculate the 50% MVC from the larger of the two MVC trials

10. Fatigue Trial
   - Participant will hold ankle dorsiflexion contraction at 50% of MVC until fatigued.
   - RA will make sure that the participant is staying at the prescribed level without encouraging them to continue, but monitoring that they are staying at the appropriate level.
   - Once the participant has fallen under prescribed value for more than 5 seconds, they will be told to stop and final time will be taken.

   **"What I would like you to do now is perform the same action you just did, but at 50% force of your maximum contraction. Looking at the monitor here, you will see that you should hold your contraction at (calculated value from MVC) for as long as you can. I want you to hold this contraction at this value until you cannot**

**hold any longer. This could take up to 5 minutes of holding the contraction or longer, depending on individual variability."**

11. Final Questionnaires:
    - Reasons for Quiting Questionnaire

**"Ok, great job. Before I get you out of the chair I would like you to fill out this final questionnaire to get an idea of how you are feeling right at this moment. It's similar to the one you did before, but if you could fill it out as you are feeling at this very moment that would be great. Thank you."**

12. De-briefing and Remuneration:

**"The primary purpose of our study is examining self-regulation and the role that various forms of depletion play in physical performance. This area of research is still very new and there are a number of theories that contribute to this area. Hopefully through this study we will be able to find out a little more about the role of self-regulation and subsequently, the depletion of."**

**"Thank you so much for your participation. Here is $20. I will need you to fill out this remuneration form to acknowledge that you did receive the money and if you would like a copy of the results you can write your email contact information on this log sheet."**