SELF-REGULATION

THE EFFECTS OF DEPLETED SELF-REGULATION ON SKILLED TASK PERFORMANCE

By: DESMOND MCEWAN, B.A. (HONS)

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Master of Science

McMaster University MASTER OF SCIENCE (2012) Hamilton, Ontario (Kinesiology)

TITLE: The Effects of Depleted Self-Regulation on Skilled Task Performance

AUTHOR: Desmond McEwan, B.A. (Hons) (Grant MacEwan University)

SUPERVISOR: Dr. Kathleen A. Martin Ginis

NUMBER OF PAGES: viii, 90

Abstract

The purpose of this study was to examine the effects of depleted self-regulation on skillful task performance. Participants completed a baseline dart-tossing task (20 tosses), and were instructed to toss as quickly and as close to the bulls-eye as possible when a particular cue light flashed. Participants then underwent a self-regulatory depleting (experimental) or a non-depleting (control) manipulation before completing a second round of dart tossing. Measures of accuracy, reaction time, and myoelectrical activity of the biceps and triceps were collected along with self-report measures of psychological resilience and trait self-control.

As hypothesized, participants in the experimental condition had poorer mean accuracy at round two than control condition participants, as well as a significant decline in accuracy from round one to round two. These effects were moderated by trait self-control; experimental group participants with higher trait self-control were more accurate in round two than experimental group participants with lower trait self-control. Experimental group participants also demonstrated poorer consistency in accuracy compared to control group participants at round two, and a significant deterioration in consistency from round one to round two. The only significant finding regarding reaction time was that consistency improved significantly for the control group but not for the experimental group.

The results of this study provide evidence that ego depletion effects occur for skill-based physical task performance, especially in regards to accuracy. These findings provide further support for the utility of the limited strength model and suggest that self-regulatory depletion can impact performance on skill-based physical tasks.

Acknowledgements

First and foremost, I must thank my parents and the rest of my family for their constant love and support in completing my Master's degree. You have always encouraged me to follow my dreams and without you, I would not be where I am today.

I would also like to thank all of my labmates for making this a great two years. All of you helped me in some way along this journey and I'm very thankful for all of the friendships and good times that were had.

I also thank my thesis committee—Dr. Steven Bray, Dr. Kelly Arbour-Nicitopoulos, and Dr. Jim Potvin—for all of your help in completing this project. Each of you generously took the time to ensure that I turned out a solid thesis.

Last but not least, thank you to my supervisor, Dr. Kathleen Martin Ginis. Coming to McMaster, I knew that I was very blessed to have the chance to work with you but I couldn't have imagined that I would be given so many incredible opportunities or learn as much as I did from you. I cannot thank you enough for everything you have done for me.

I dedicate this thesis to my grandma, Doreen. I miss you and your smile.

Table of Contents

Lists of Figures and Tables

Tables

Figures

Introduction

Self-regulation (or "self-control") refers to any effort by a human being to alter its own inner states or responses, including actions, thoughts, feelings, desires, and task performances (Baumeister, Heatherton, & Tice, 1994). A high value is placed on self-regulation as it liberates humans from being automatic, robotic, and instinctual beings and, thus, carries great weight in determining how individuals behave throughout their lives (Muraven, Baumeister, & Tice, 1999; Suchy, 2009). In adolescence, those with higher self-control tend to obtain better grades, intelligent quotient (IQ) scores, and academic standardized test scores than those with poorer self-control (Funder & Block, 1989; Shoda, Mischel, & Peake, 1990). During one's college years, self-control has been associated with academic performance, effort, positive time management, and the improved use of learning strategies and a supportive study environment (Bembenutty & Karabenick, 1998; Tangney, Baumeister, & Boone, 2004). Later in adulthood, greater self-control predicts more success in the workplace, stronger exercise adherence, and better personal relationships (Dishman, Ickes, & Morgan, 1980; Finkel & Campbell, 2001; Tangney et al., 2004). By contrast, self-regulatory failures are associated with a wide range of negative outcomes, from overeating and smoking to violent criminal behaviour and even the attainment of certain chronic diseases (Baumeister et al., 1994; Hagger, Wood, Stiff, & Chatsizarantis, 2010a; Muraven, Tice, & Baumeister, 1998). Indeed, evidence from many domains within the social sciences reveals how an individual's self-regulation can have a profound impact on numerous outcomes across his/her lifespan.

The Limited Strength Model of Self-Regulation

In order for individuals to overcome the force of their habitual or normal responses, they must draw on a personal resource or strength (Baumeister & Heatherton, 1996; Baumeister et al.,

1994). This resource has been conceptualized as *self-regulatory strength* and is akin to the colloquial concept of willpower. It has been suggested that self-regulatory strength is a global, finite, and renewable central nervous system resource that has a limited capacity (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven et al., 1998). While the exact location of this resource is not conclusively known, it has been theorized to be under executive control in the prefrontal cortex (Banfield, Wyland, Macrae, Munte, & Heatherton, 2004; Bray, Martin Ginis, Hicks, & Woodgate, 2008; Gailliot, Baumeister, DeWall, Maner, Plant, Tice, et al., 2007; Inzlicht & Gutsell, 2007). This hypothesis arises from the fact that executive functioning plays a role in individuals' abilities to make choices (such as initiating and inhibiting particular responses), coordinate actions, attend to stimuli, and plan and engage in purposeful, effortful, goal-directed, and future-oriented behaviours (Schmeichel & Baumeister, 2004; Suchy, 2009)—these behaviours are key components of self-regulation. As will be discussed further, research has consistently shown that self-regulatory depletion affects task performance by impairing the prefrontal cortex regions of the brain that are involved in the performance of tasks that require self-regulation (Wagner & Heatherton, 2011). Individuals with impairments in executive functioning can experience a wide array of consequences, from not studying for an upcoming exam to having a poorer ability to plan motor behaviours to engaging in abnormal and potentially dangerous social behavior (Suchy, 2009; Wagner & Heatherton, 2011).

According to the *limited strength model*, it is thought that this self-regulatory resource is drained or depleted when an individual regulates his/her behaviours, including thoughts, emotions, attention, and physical performances. At such time, the individual will have a poorer ability to perform subsequent behaviours that require self-regulation and may experience lapses in executive functioning, such as engaging in behaviours that are incongruent with their

behavioural intentions or goals (e.g., eating unhealthy foods or not exercising despite the goal of losing weight). It is, therefore, necessary to rest the resource until it has been adequately replenished. A common way of describing self-regulatory depletion is to use the analogy of a muscle (Baumeister et al., 1998; Baumeister, Muraven, & Tice, 2000; Baumeister, Vohs, & Tice, 2007). If an individual wishes to lift a weight with his arms, for example, he will require a sufficient amount of strength in the arm muscles. After repeatedly lifting this weight however, the muscle will become fatigued and he will be unable to lift the weight adequately until he has rested. Likewise, an individual can only exert a certain amount of self-control until he becomes depleted; at this point he will be unable to effectively perform a self-regulatory task until he has recuperated. Furthermore, as a global resource, all tasks that require self-control are affected by self-regulatory depletion (Baumeister et al., 1998). Hence, if an individual's self-regulatory reservoir is depleted via a cognitive task, for example, he will suffer decrements on a task requiring self-control, even if the task is in a different domain, such as a physical task. This failure to self-regulate due to a depletion of one's self-regulatory resource is commonly referred to as *ego depletion* (Baumeister et al., 1998).

University students could likely speak to the effects of self-regulatory depletion and how this deteriorates their performance on a variety of tasks. For example, a student may have recently developed a goal of exercising after her classes throughout the week. Although somewhat reluctant because her friends go out for drinks at this time, she knows that exercising is good for her and she may succeed in adhering to her exercising intentions on most days. However, during certain times of the semester (e.g., exam time), she may find that maintaining this regimen and engaging in her goal-directed behaviour is quite difficult. After a long day of exerting self-control to attend classes, engage in hours of studying, and complete a couple of

exams, she may find it much easier to give into her desire to skip her workout and hang out with friends instead. Or, if she still summons enough willpower to get herself to the fitness centre, she made find that, in comparison to other days, she is unable to run as long or at as great of an intensity, or that she has to work harder to lift her usual weights. This example demonstrates how the depletion of an individual's self-regulatory resources via self-regulation in one domain (e.g., studying) affects her self-regulation and task performance in another domain (e.g., exercising).

Depleted Self-Regulation and Task Performance

Numerous studies have been conducted to test the limited strength model. Typically, these effects are tested using a two-task paradigm (Hagger, Wood, Stiff, & Chatzisarantis, 2010b). In these experiments, participants in an experimental group perform an initial task that requires self-regulation, while those in the control group engage in a similar task that does not require self-regulation. Thus, participants' self-regulatory resources are depleted in the experimental group but not in the control group. Following a short break, participants in both groups perform a second task requiring self-regulation (i.e., the dependent measure) to test for ego depletion. Support for the limited strength model is evident if participants in the experimental group perform poorer on the second task than participants in the control group.

Baumeister and colleagues (Baumeister et al., 1998; Muraven et al., 1998) initially tested the limited strength model in a series of experiments. In one study by Muraven et al. (1998), participants who were told to not think about a white bear (i.e., were required to engage in cognitive regulation) were worse at regulating their emotions when they watched a humourous video (i.e., trying not to smile or laugh), thereafter. A second study found that participants who were instructed to engage in a similar type of thought-suppression demonstrated poorer cognitive

persistence on a subsequent unsolvable anagram task than those who were not initially told to suppress any thoughts. Similarly, Baumeister et al. (1998) found that participants who were instructed to eat radishes and resist eating more appealing chocolate chip cookies (i.e., engage in behavioural regulation) also demonstrated poorer subsequent perseverative behaviours compared to individuals who were free to eat whatever they liked (i.e., were not required to regulate their behaviours). The depleted participants in this experiment also showed poorer perseverance on a solvable anagram task than non-depleted participants. Thus, even though the first and second tasks in these studies were different, the manipulation of depleting individuals' self-regulatory resources in the first task seemed to impair their executive functioning for completing the second task. This resulted in deleterious performance on the second task requiring self-regulation. These seminal studies provided preliminary support for the strength model of self-regulation by demonstrating that depleted self-regulation predicted performance decrements on numerous ensuing self-regulatory tasks.

More pertinent to the proposed study, depleted self-regulation has also been shown to have a detrimental effect on the subsequent performance of physical tasks. Indeed, another study conducted by Muraven et al. (1998, study 3) found that participants who were instructed to suppress their emotional responses to an upsetting movie (i.e., engage in emotional regulation) were unable to sustain an isometric handgrip squeeze for as long as those who were not initially told to regulate their emotions. These results have since been corroborated by a number of researchers who have used a handgrip squeeze task as the dependent measure for testing the effects of ego depletion (e.g., Bray et al., 2008; Muraven & Shmueli, 2006; Vohs, Baumeister, & Ciarocco, 2005). Further, Martin Ginis & Bray (2010) found that the amount of work output generated on an aerobic task (a stationary bicycle) was less for participants who previously

completed a cognitively-depleting task than for those who initially completed a non-depleting cognitive task. The results of these studies, thus, demonstrate that decrements on motor tasks could even occur when an individual's self-regulatory resources had been depleted by an unrelated, cognitive task. This collection of research supports Baumeister and colleagues' proposition that all behaviours—physical, emotional, cognitive, etc.— requiring self-regulation draw on the same resource that has a limited reservoir.

Self-Regulation and Skill-Based Physical Performance

In addition to the evidence for ego depletion across a wide range of domains within the social sciences, sports enthusiasts could likely provide a plethora of anecdotal evidence of depleted self-regulation affecting athletic performance. For example, in the eighth end of a semifinals match at the 2011 Men's World Curling Championship, Team Canada was in a close game (leading 3-2) against Team Scotland. After releasing his first shot of the end, Team Scotland Skip, Tom Brewster—who, at the time, had a much better shooting percentage (88%) in the match than Canadian Skip, Jeff Stoughton (76%)—called his Lead and Second (i.e., the players who sweep the rock down the ice) to stop sweeping as the stone made its way to the rings. However, there was a miscommunication between the Skip and his sweepers and, as a result, they continued to sweep. After repeatedly yelling for them to stop, the players ceased sweeping; however, the stone continued to an unfavourable position in the rings.

After the shot, Brewster verbally chastised his teammates, yelling, "if I'm shouting you off, [get] off! Okay!?" Team Canada proceeded to steal a point in that eighth end and for the remainder of the match, Team Scotland seemed very out of sync by numerous observers. In addition, Brewster missed a relatively easy open hit in the ninth end, essentially handing over the 5-2 victory to the Canadian team. One of the telecast's commentators and former world curling

champion, Linda Moore, remarked: "He [Brewster] was playing so well but got that very emotional moment in eight where he missed his first [shot]; two of the next three [shots] were not good throws." This example suggests that depleted self-regulation may play a role in skilled task performance. Based on the limited strength model, it may be that Brewster had exhausted all of his self-regulatory resources throughout the match (e.g., perhaps by previously resisting the urge to express frustration with his teammates or previously suppressing negative thoughts after making a mistake), which contributed to his inability to (a) control himself from his emotional outburst towards his teammates and (b) successfully execute his relatively straightforward shot.

In addition to anecdotal reports, researchers have proposed a potential connection between self-regulation and athletic performance. For instance, Baumeister el al. (1994) suggested that self-regulatory failures may be a potential cause of performing poorly in high-pressure circumstances (i.e., "choking") in sports. Later, Jordet (2008) analyzed self-regulatory strategies of soccer players in penalty shootouts. It was found that players who engaged in poorer or misguided self-regulatory strategies (e.g., looking away from the opposing goalkeeper and quickly taking their shots rather than taking their time to properly line up their shots) were less likely to score on their penalty kicks than those who used more appropriate pre-shot strategies. While these studies certainly provide valuable insight and some indirect evidence of the importance of self-regulation in sports, research on whether depleted self-regulation actually results in poorer athletic performance has not yet been conducted. As athletes must often regulate their emotions, cognitions, attention, and behaviours, these effects are certainly worth investigating. Studies that have analyzed one's regulation of one's emotions, cognitions, attention, and behaviour have found each of these to be positive contributors for performing at an optimal level in sports (e.g., Baumeister & Showers, 1984; Hatzigeorgiadis, Theodorakis, &

Zourbanos, 2004; Lazarus, 2000). However, in line with the limited strength model, if individuals' self-regulatory resources are depleted via constant self-regulation, this may actually result in a *poorer* ability to perform a subsequent task that requires self-regulation optimally and obtain desired results.

While it has been shown that depleted self-regulation impairs the performance of *muscular endurance-based* physical tasks (e.g., sustaining an isometric hand squeeze), which is unquestionably part of athletic performance, it is critical to determine whether similar decrements are evident for *skill-based* aspects of task performances. Depending on the type of task, this could involve assessing performance on numerous measures, such as accuracy and reaction time, both of which are important factors for successful performance in sports. For instance, a baseball pitcher must be extremely accurate with his pitches to ensure that the opposing batter cannot hit the ball and that the pitch will result in a strike. A pitch that is thrown just a few mere inches off-track could result in a successful hit by the opposing batter rather than a strike. In addition, the pitcher's counterpart, the batter, must have extremely good reaction time if he is to hit the baseball successfully. This would involve identifying the stimulus (i.e., the speed and type of pitch thrown), deciding whether to swing or not (which would involve response selection and inhibition), and then physically executing his decision accordingly. An error at any of these stages, such as deciding to swing at an inappropriate pitch (e.g., one that would have landed far outside the strike zone) or a slow physical execution after deciding to swing, is likely to result in failure for that batter's particular swing. There are many other examples in which an athlete's accuracy and reaction time are equally important, such as a hockey player on a breakaway (e.g., she must identify when and where there is an opening on the goaltender and shoot against her quickly and accurately), a basketball player (e.g., he must

identify when a teammate is open and make an accurate pass before the defenders recover), and a soccer goalie (e.g., in a penalty shootout, she must select exactly where she thinks the shooter is kicking the ball and react sufficiently so that she can make the save before the ball sails past her hands).

The above examples also highlight how self-regulation is involved in many skill-based sports tasks. Indeed, there are numerous behaviours under executive control that play a role in successfully carrying out skilled performances. For instance, in order for a football quarterback to complete a pass to his opponent, he must regulate his attention (e.g., attending to certain players on his and the opposing team, while ignoring task-irrelevant cues), engage in response inhibition (e.g., waiting for a receiver to get open rather than erroneously forcing a pass) and initiation (e.g., deciding to pass to an open receiver), and plan his behaviour appropriately (e.g., accurately aiming his throw to a particular receiver). When a receiver becomes open, the quarterback must react quickly and throw the ball accurately to his receiver before the defense is able to react and recover. Lapses in a quarterback's executive functioning may result in him being unable to achieve his goal of successfully completing a pass to his receiver.

From the aforementioned examples, the question remains: does performance on these types of skill-based sports tasks that require self-regulation deteriorate when individuals' self-regulatory resources are depleted? As many tasks in sports require executive control and the depletion of self-regulation is thought to impair executive functioning, it would seem that such ego depletion effects are tenable. Testing the effects of self-regulatory depletion on athletic performance should first begin with a basic, skill-based task to see if comparable ego depletion effects exist for this type of task as they do for other tasks (e.g., endurance-based physical task performance). Then, if initial evidence for depleted self-regulation affecting skillful task

performance is established, further research of its effects in more specific sporting tasks could be conducted. If such evidence for this principle were found, this would be a novel and valuable contribution to the existing literature of ego depletion and also extend to other skill-based domains. For instance, consider the highly skilled task of medical surgery. Surgeons must exert considerable self-regulation while they complete this extremely important undertaking. It would, thus, be extremely important to determine whether depleted self-regulation negatively affects their ability to perform skill-based tasks at an optimal level, as their patients' lives are literally in their hands.

Potential Physiological Mediators of Ego Depletion

While substantial evidence supports the effects of ego depletion in many areas, research that tests for potential explanations of these effects is in its infancy. As such, the question remains as to why the depletion of individuals' self-regulatory resources at a central executive control level affects their performance on a physical task that is carried out by the peripheral muscles. This is a particularly important research question that should be addressed. Going back to the analogy of a muscle, it has been found that when an individual performs a resistance exercise such as a bicep curl, his muscle becomes fatigued; he is then unable to perform a bicep curl or similar exercise until sufficiently rested. Research has shown that part of the reason for this fatigue is that the resistance exercise causes the muscle's glycogen stores to be depleted and the muscle enters a state of catabolism (i.e., it is broken down; Haff, Lehmkuhl, McCoy, & Stone, 2003). By knowing that glycogen depletion is one of the mechanisms for why resistance exercise results in muscular fatigue, researchers have sought to discover solutions to prevent this depletion so that athletes can exercise longer before getting fatigued. For instance, ingestion of carbohydrates during exercise has been found to be a beneficial way of offsetting glycogen

depletion (Haff et al., 2003). By contrast, while the effects of ego depletion are clearly evident, the reasons for these effects require research. Knowing the mechanisms by which ego depletion transpires would allow researchers to examine potential ways to prevent these negative effects from occurring or alleviating them if they do occur.

While there is a prevailing hypothesis that depleted self-regulation results in poorer task performance due to impairments in executive functioning, it has also been proposed that—for physical tasks—there may be a psychophysiological component to ego depletion. For instance, Bray et al. (2008) hypothesized that the ego depletion effects observed in studies of endurance-based physical task performance may be due, in part, to self-regulatory depletion increasing the myoelectrical (EMG) activation of one's muscles. Electromyography measures the electrical activity produced by the skeletal muscles (Basmajian & Luca, 1985). An increase in EMG amplitude indicates a greater recruitment in the number of skeletal muscle motor units. It is thought that this increase in neuromuscular activation may result in decreased physical task performance, such as one's ability to sustain an isometric handgrip (an endurance-based task; e.g., Bray et al., 2008; Larsson, Larsson, Zhang, Cai, & Oberg, 1995) or successfully execute a golf putt (a skill-based task; e.g., Cooke, Kavussanu, McIntyre, & Ring, 2010; Weinburg & Hunt, 1976). Consistent with their hypotheses, Bray et al. (2008) found that participants who were in a self-regulatory depleting condition were unable to sustain an isometric handgrip for as long of a duration as participants in the control condition; depleted participants also required greater muscle activation to sustain the handgrip than controls. This provided preliminary evidence that muscular activation may be related to the ego depletion effects observed for endurance-based physical tasks. Determining if muscle activation plays a role in the effects of depleted self-regulation on skill-based tasks is yet to be assessed.

Potential Moderators of Ego Depletion

Trait self-control. As previously mentioned, higher levels of self-control are associated with numerous positive outcomes, such as exercise adherence, better interpersonal relationships, and success in school and the workplace (Dishman et al., 1980; Finkel & Campbell, 2001; Tangney et al., 2004). The limited strength model proposes that continual self-regulation can bring about a "state depletion" of individuals' self-regulatory resources, which can result in a temporary failure to obtain these positive outcomes (Hagger et al., 2010a). However, researchers have also suggested that self-control is a dispositional trait that varies between individuals (Funder, Block, & Block, 1983; Tangney et al., 2004; Wills & Dishion, 2004). Thus, certain individuals may have a greater capacity to self-regulate than others. That is, individuals with higher dispositional self-control are thought to have a better ability to perform a task requiring self-regulation after they have been depleted compared to those with lower dispositional self-control. In other words, greater trait self-control may protect individuals from the deleterious effects of ego depletion.

To test for the moderating influence of trait self-control, researchers have had participants complete the Trait Self-Control scale (Tangney et al., 2007) after they completed a dual-task experimental paradigm. Overall, mixed results have been found. A clear interaction between condition and trait self-control has emerged in some studies (e.g., Dvorak & Simons, 2009; Gailliot & Baumeister, 2007; Gailliot, Schmeichel, & Maner, 2007), while other studies have found no such interaction (e.g., Gailliot & Baumeister, 2007; Stillman, Tice, Fincham, & Lambert, 2009). The meta-analysis by Hagger et al. (2010a) was unable to calculate an effect size for the studies that have assessed trait self-control as a possible moderator of the ego-depletion effects due to a limited number of tests of the effect. However, the authors suggest that

the moderating role of trait self-control is consistent with the limited strength model. Just as certain individuals with stronger muscles have a better ability to lift a weight after they have been fatigued compared to those with weaker muscles, individuals with greater self-regulatory strength may be better able to self-regulate when their resources have been depleted compared to those with a lesser self-regulatory strength. Hagger et al. (2010a) recommended that future research be conducted to test for the interaction between ego depletion and trait self-control.

Psychological resilience. Resilience has been defined as an individual's ability to cope with stress or adversity and "bounce back" to a previous state of normal functioning (Masten, 2009). Examples of resilience in sports could be an athlete's ability to perform well while mentally fatigued, following a previous poor performance, or—more pertinent to the current study—after his/her self-regulatory resources have been depleted. Although the literature on psychological resilience is wide ranging across many domains within the social sciences, its study in sports is relatively limited (Gucciardi, Jackson, Coulter, & Mallett, 2011). This is surprising as the ability to bounce back from negative events is a defining characteristic of successful, high performance athletes (Gould, Dieffenbach, & Moffett, 2002). Indeed, many coaches, sport psychologists, sports commentators, and athletes have commented on the importance of resilience within sports. For example, Vince Lombardi—who is arguably the greatest American football coach of all-time—said, "it's not whether you get knocked down; it's whether you get back up." Consider a football quarterback who throws a perfect pass in the corner of the endzone to his receiver. However, the referee erroneously rules that the catch was made out of bounds, thus erasing the touchdown. At this point, the quarterback is likely feeling frustrated and angry and must exercise self-control to not yell at the referee and draw a penalty—this self-regulation depletes his self-regulatory resources and (in alignment with the hypotheses

of the current study) would be detrimental to his subsequent performance. His ability to "bounce back," forget about the poor call, and return to an ideal state after he has been depleted is imperative if he and his team are to be successful on the next play and thereafter.

Studies of resilience in sports have been conducted to: assess athletes' perceptions of the important factors involved in being resilient (e.g., Galli & Vealey, 2008); test how athletes respond to adversity (Seligman, Nolen-Hoeksema, Thornton, & Moe-Thornton, 1990), negative feedback (Martin-Krumm, Sarrazin, Peterson, & Famose, 2003) and serious injury (e.g., Podlog & Eklund, 2006; 2009); and determine if psychological skills training can help improve their resilience (e.g., Schinke & Jerome, 2002; Schinke, Peterson, & Couture, 2004). Most relevant to the current study, Mummery, Schofield, & Perry (2004) examined a cohort of national swimmers who were identified as belonging to one of three groups: those who were successful after initially failing (i.e., resilient); those who were unsuccessful after initially failing (i.e., non-resilient); or those who were initially successful. An intriguing finding was that swimmers in the resilient group had a better physical self-concept than non-resilient and initially-successful swimmers. As greater self-concept has been shown to be positively related to performance in sports (e.g., Marsh, Gerlach, Trautwein, Ludtke, & Brettschneider, 2007), the results from this study seem to provide some indirect, preliminary evidence of the positive relationship between resilience and performance. Recently, Gucciardi et al. (2011) developed an adapted version of the Connor-Davidson Resilience questionnaire (Connor & Davidson, 2003) and tested its reliability and validity in a sample of cricketers. Their analyses confirmed the usefulness of this measure in assessing resilience, thus providing a valuable scale for measuring individuals' psychological resilience in a sporting context.

As a seemingly important construct in sport, further research on psychological resilience and its effect on skilled performance is warranted. Specifically, it would be interesting to determine whether resilient individuals are better able to bounce back from self-regulatory depleting situations than less resilient individuals. Going back to the analogy of a muscle, some individuals may be better able to recover and again perform an exercise task that requires the use of the muscle they had just fatigued. Likewise, it may be that some individuals have a better ability than others to "refuel" their self-regulatory resources and perform a subsequent task requiring self-regulation. It would, therefore, be valuable to set up an experimental manipulation in which individuals' performance on a sports task is assessed after a self-regulatory depleting situation and determine whether individuals' levels of psychological resilience (as measured by the Connor-Davidson Resilience questionnaire) moderate the hypothesized effects of ego depletion on the performance of a skill-based physical task.

The Current Study

Using a controlled experimental design, the primary purpose of this Master's project was to extend previous research on the detrimental effects of depleted self-regulation on physical exertion tasks by determining if similar ego depletion effects occur for skilled task performance. In addition, we assessed potential moderators—trait self-control and psychological resilience—of the anticipated ego depletion effects. Lastly, we sought to determine whether depleted self-regulation would result in increases in muscle activation.

We used performance on a dart-tossing task as our dependent measure, as this is a skill-based, physical sports task that is often used in experimental studies that test novel hypotheses in sport psychology (e.g., Radlo, Steinberg, Singer, Barba, & Melnikov, 2002; Van Raalte, Brewer, Lewis, Linder, Wildman, & Kozimor, 1995; Zimmerman & Kitsantas, 1997). The dart-tossing

task was modified by having three different colored lights above the dartboard—participants were instructed to toss only when a particular light flashed and to toss as quickly as possible upon seeing that light (described in further detail in the **Procedure** section). This additional caveat of forcing individuals to make quick decisions (to toss or resist tossing) upon seeing a light flash ensured that the task was (at least partially) under executive control and demanding of their self-regulatory resources. This also provided us with two measures of performance: accuracy (i.e., distance from target) and reaction time (i.e., time between the onset of the cue light to toss and initial movement of the arm). This task also allowed us to connect EMG electrodes to a participant's throwing arm to measure EMG activity. This would have been much more difficult to complete with other more complicated and/or gross movement tasks. Furthermore, we wanted to use a task that would be somewhat familiar or recognizable to most people. We anticipated that most, if not all, people would know what dart tossing is and many would have likely played at some point during their lives. Finally, dart tossing is a challenging yet relatively straightforward task; the goal in regulation darts is, quite simply, to toss as accurately as possible. Because of this, we felt that the majority of participants would be able to at least attempt the task without much difficulty.

In short, participants: (1) completed an initial round of a self-regulatory demanding dart-tossing task consisting of 20 tosses during which the EMG activity of their biceps and triceps was recorded; (2) were assigned to either a self-regulatory depletion (experimental) or non-depletion (control) condition; (3) completed a second round of the self-regulatory demanding dart-tossing task consisting of 20 tosses during which the EMG activity of their biceps and triceps was recorded; and (4) completed the Trait Self-Control (Tangney et al., 2007) and Connor-Davidson Resilience (Gucciardi et al., 2011) questionnaires. The primary hypothesis of

this study was that those in the experimental condition would show poorer performance on the second round of dart tossing (in terms of mean accuracy and reaction time) than those in the control condition due to the depletion of experimental group participants' self-regulatory strength. It was also hypothesized that these performance decrements would be moderated by trait self-control and resilience; that is, experimental group participants with higher trait self-control as well as those with greater resilience would show better accuracy and reaction time, post-manipulation, than those who scored lower on these measures. Moreover, it was hypothesized that control group participants would be more consistent across the 20 tosses at round two in terms of accuracy and reaction time. Finally, it was hypothesized that experimental group participants would have greater myoelectrical activation in their biceps and triceps during the dart-tossing task compared to control group participants.

Method

Participants

A medium-to-large effect size was expected for this study based on the meta-analysis by Hagger et al. (2010a) on the effects of ego depletion for an isometric handgrip squeeze (Cohen's $d = 0.64$). Although this is a different task than dart tossing, this was the only effect size that was calculated for performance on a physical task in this meta-analysis; as such, it was the estimate for an expected effect size in the current study. Based on Cohen's (1992) tables, 60 participants (30 per condition) were required to have 80% power to detect significant differences between groups (ES = .80; $\alpha = .05$) on the dependent measures. Participants were recruited via posters placed around the McMaster campus (Appendix A) and emails sent to individuals who participated in previous studies within the exercise psychology laboratory at McMaster and who had given permission to be contacted for future studies (Appendix B).

Apparatus

A regulation dartboard and dart was used for this task. As per standard rules, the dartboard was hung so that the bulls-eye was 1.73 meters from the floor, with tosses taken 2.37 meters from the dartboard (Official Rules of Darts, 2011). There was also a box with three lights colored green, red, and yellow placed above the dartboard. This was connected to a control panel, which the experimenter operated to flash each of the lights. The control panel was also connected to the EMG amplifier.

Measures

Task performance. Performance on the dart-tossing task was determined by measuring participants' accuracy and reaction time. Using a tape measure, accuracy was defined as the distance at which each toss landed from the center of the bulls-eye target (in centimeters). Reaction time was measured using custom analysis software and was calculated as the time elapsed from the onset of the cue light signal (i.e., the green light in the first round and the red light in the second round) to the initiation of activation in either the biceps or triceps (whichever was initiated first). To determine the initiation of activation, the experimenter noted the time when the muscle activity of the biceps or triceps increased above a threshold level of 1.5 standard deviations greater than resting activity (as per Hodges & Bui, 1996). For each participant, reaction time scores for each toss were calculated twice to ensure consistency in the experimenter's measurements. An intraclass correlation coefficient (ICC) was computed and revealed high consistency between these two calculations, ICC = .992. Our primary measure of performance was participants' means for accuracy and reaction time for each round. Secondarily, we measured how consistent participants were on the dart-tossing task by calculating the standard deviations for accuracy and reaction time for each round.

Muscle activity. Five disposable adhesive surface EMG electrodes of 3 centimeters in diameter were connected to the participant's tossing arm. One ground electrode was placed on the participant's lateral epicondyle; two electrodes were placed next to each other lengthwise on the belly of the biceps brachii and two were placed next to each other on the lateral head of the triceps brachii—the center-to-center distance between the two electrodes on each muscle was 3 centimeters. By having two electrodes at the muscle sites (i.e., bipolar detection), the voltage waveform that was recorded was the difference in action potential between the two electrodes.

Data were collected with LabChart7 software (AD Instruments, Bella Vista, NSW, Australia) using a PC laptop computer and converted by a 12-bit A/D card (AD Instruments, Bella Vista, NSW, Australia). Surface EMG signals were processed through a differential amplifier (input impedance = 200 mΩ, 0.3 – 1000 Hz, CMRR = 85 dB at 1 – 60 Hz, AD Instruments, Powerlab 8/30, Bella Vista, NSW, Australia). EMG signals were dual-pass filtered (20 – 500 Hz), full-wave rectified, and filtered using a sixth order Butterworth filter with a cut-off of 1.5Hz.

For each toss, muscle activity was determined by taking the peak myoelectrical activation of the biceps and triceps. Prior to the first round of dart tossing, participants completed a maximum voluntary contraction for both the biceps and triceps (described in further detail in the **Procedure** section). Completing these MVCs allowed us to obtain a normalized signal of EMG amplitude for each toss by taking the peak activation of the biceps and triceps and dividing these by the maximum force value generated by the MVCs. By obtaining a normalized EMG signal, we were able to subsequently compare the muscle activation of participants in the experimental and control groups. For both rounds of tossing, a mean normalized value of participants' peak activation for the biceps and triceps was obtained.

Demographic questionnaire. Participants were asked to provide their age, sex, and previous experience playing darts (Appendix D).

Manipulation checks. Participants completed three manipulation checks after the experimental manipulation task to determine whether there were any differences between groups in terms of perceived effort, fatigue, or mood. These variables have been assessed in previous studies of ego depletion (Hagger et al., 2010a) and it is important to rule these out as alternative explanations (i.e., as opposed to self-regulatory depletion) for the hypothesized ego depletion effects. For example, if participants in the experimental group performed poorer in the second round of dart tossing but also felt more fatigued compared to the control group participants, it could be argued that the between-group differences in round two accuracy and/or reaction time were due to the differences in fatigue, rather than self-regulatory depletion itself.

Perceived effort. Borg's CR-10 scale (Borg, 1998) was employed for participants to estimate how much mental exertion they believe they expended during the manipulation task (Appendix F). The single-item revised scale starts at zero ("extremely weak") with variable increases to ten ("absolute maximum"). Hence, higher scores indicate more perceived mental exertion. This scale was originally developed to measure perceived physical exertion (Borg, 1998), however, it has since been validated in studies assessing mental exertion as well (e.g., Larsby, Hällgren, Lyxell & Arlinger, 2005).

Fatigue. Participants' perceived level of fatigue was assessed using the Visual Analogue Scale (VAS; Lee, Hicks, & Nino-Murcia, 1991; Appendix G). The VAS consists of a 100-millimeter horizontal bar, with "extremely tired" on the left side of the bar and "extremely energized" on the right side. Participants indicate how fatigued they feel after completing the manipulation task by drawing a vertical line through the bar. A score is then obtained by

measuring how far (in millimeters) the line is from the right side of the bar, with greater distances indicating more perceived fatigue. This measure is simple yet valid and reliable in assessing individuals' level of fatigue (Carlsson, 1983; Lee et al., 1991).

Mood. Participants' mood after completing the manipulation task was assessed with the 16-item Brief Mood Inspection Scale (BMIS; Appendix H; Mayer & Gaschke, 1988). Each item has an adjective describing a particular mood (e.g., "lively," "happy," "jittery," etc.). Participants indicate the level to which this statement describes their current mood from 1 ("Definitely do not feel") to 7 ("Definitely do feel"). Four subscale scores are obtained from this questionnaire: the *pleasant-unpleasant* (P-U) scale sums items 1, 2, 3, 4, 5, 6, 10, and 16 and subtracts scores from the remaining items; the *arousal-calm* (A-C) scale adds items 1, 2, 3, 5, 6, 9, 11, 12, 13, and 14 together and subtracts scores from the other items; the *positive-tired* (P-T) scale adds items 1, 2, 3, 5, and 6 together and subtracts scores from the remaining items; and the *negative-relaxed* (N-R) scale sums items 9, 11, 12, 13, and 14, and subtracts the remaining items' scores. This scale has demonstrated validity and reliability in assessing individuals' moods (Mayer & Gaschke, 1988).

Moderators

Trait self-control. The 13-item Brief Trait Self-Control scale (TSC; Appendix I; Tangney et al., 2004) was used to assess trait self-control. This questionnaire consists of 13 items with participants indicating the degree to which they believe each statement (e.g., "I am good at resisting temptation") applies to them from 1 ("not at all like me") to 5 ("very much like me"). Questions 2, 3, 4, 5, 7, 9, 10, 12, and 13 are reverse-scored. All items are then summed with higher scores indicating greater self-control (possible range = 13-65). This scale has been shown

to be valid and reliable in assessing individuals' dispositional self-control (Tangney et al., 2004). In the current study, Cronbach's alpha was .78.

Psychological resilience. The revised 10-item Connor-Davidson Resilience Scale (CD-RISC; Appendix J; Connor & Davidson, 2003; Gucciardi et al., 2011) was used to measure individuals' psychological resilience. On this questionnaire, participants indicate the degree to which they feel each item is representative of them from 0 ("not at all like me") to 4 ("very much like me"). The items are then summed to derive a total score (possible range = 0-40), with higher scores indicating better psychological resilience. This revised scale has proven to be valid and reliable in assessing individuals' levels of resilience (Connor & Davidson, 2003; Gucciardi et al., 2011). In the current study, Cronbach's alpha was .78.

Procedure

Upon giving written consent to participate in the study, participants completed the demographic questionnaire. After cleansing the skin with an alcohol pad, five EMG electrodes were connected to the participant's throwing arm (as previously described in the **Muscle activity** section) to measure muscle activation during the two rounds of dart tossing. Participants then completed a maximum voluntary contraction (MVC) for their biceps by initially placing their arm at their side with a 90-degree bend at the elbow and with their palm facing upward; they then squeezed their biceps with as much force as possible (as if they were completing a biceps curl), while the experimenter provided appropriate resistance. Similarly, the participant completed a MVC for their triceps by again placing their arm at their side with a 90-degree bend at the elbow and with their palm facing inwards (i.e., medially); the participant then extended their triceps downwards with as much force as possible (as if they were completing a triceps extension), while the experimenter provided appropriate resistance.

Participants were then given two to three minutes to practice tossing the darts. To make the task demanding of participants' self-regulatory resources, participants were instructed to take each toss when they saw the green light flash; thus, they had to resist the temptation to toss the dart when they saw the red or yellow light flash. Participants were also instructed to react as quickly as possible when they saw the cue that indicated for them to toss. The experimenter then ensured that the participant understood the procedure (i.e., when they were to toss the dart) and commenced with the first round of dart tossing (20 tosses).

For each toss, the experimenter asked the participant if he/she was ready to begin. Upon agreement, the experimenter said "begin" and began recording EMG activity. There was a one-, four-, seven-, or ten-second interval between the point when the experimenter said "begin" and when the green cue light flashed. To ensure consistency across participants (thus avoiding a potential confound), the foreperiod of each toss was the same for each participant. (A description of this order, which was randomly determined, can be found on the scoring sheet in Appendix K.) Muscle activity readings for each toss were stopped once the dart hit the dartboard. At this point, the experimenter measured how far the dart landed from the bulls-eye, retrieved the dart from the dartboard, and handed it to the participant for the next toss. This procedure was repeated for each toss until the round was completed. Although participants were able to see the experimenter measuring the distance between the dart and the bulls-eye, they were not given any verbal feedback regarding their accuracy or reaction time.

Participants were then randomly assigned (by the experimenter drawing a small piece of paper labeled "experimental" or "control" out of a hat) to either a self-regulatory depleting (experimental) condition, or to a non-depleting (control) condition. A modified Stroop task was used as the experimental manipulation in this study. This task has been used in our laboratory

(Bray et al., 2008; Martin Ginis & Bray, 2009) as well as in Baumeister's seminal studies (Wallace & Baumeister, 2002) as a means of depleting individuals' self-regulatory resources. In this task, participants are presented with lists of color words (e.g., red, blue, green) and required to read aloud the color of the print ink and ignore the text for each word presented. However, when participants encounter a word printed in red ink, they are required to override the general instructions and read aloud the printed word. In the depleting (i.e., experimental) condition, the print ink color and printed text are mismatched. For example, the word "BLUE" may be presented in yellow ink color—the correct verbal response in this case would, thus, be "yellow." However, when the word "BLUE" is presented in red ink, the correct verbal response would be "blue." In the non-depleting, control condition, the words are matched (e.g., the word "BLUE" is presented in blue ink, "RED" is presented in red ink, and so on). Sample items can be found in Appendix E.

The experimenter explained the Stroop task and provided a few examples. The participant then practiced a few examples to confirm that they understood the task. In both conditions, the participant was given the same instructions (i.e., to call out the colour of the word rather than the printed word itself; however, if printed in red ink, he/she was to call out the printed word rather than the colour). The participant was given the respective Stroop cards (i.e., congruent or incongruent) and the trial began. The participant called out the colours and the experimenter followed along on a scoring sheet to ensure that the task was being completed correctly. In both conditions, the Stroop task was carried out for five minutes. Upon completion of the Stroop task, participants completed the manipulation check questionnaires (i.e., the RPE, VAS, and BMIS).

Participants then completed a second round of dart tossing. The protocol for this round was almost identical to the first round—participants took 20 tosses aiming for the bulls-eye, while their muscle activity was recorded. However, instead of tossing on the green light, participants were instructed to toss on the red light, as such a rule change has been shown to be demanding of individuals' self-regulatory resources (Hall, Fong, Epp, & Elias, 2008).

After the second round of tossing, participants completed the trait self-control and psychological resilience questionnaires. Participants were then debriefed, given a written debrief form (Appendix L), and given a $20 remuneration. The duration of each experimental session was approximately 30 minutes.

Data Analyses

The following section describes each of our hypotheses and the analyses used to test each of these hypotheses. For all tests, alpha was set at .05.

Hypothesis 1: participants in the experimental condition would show poorer overall accuracy in round two compared to participants in the control condition. A 2 (time) X 2 (condition) Repeated Measures ANOVA was conducted to test this hypothesis. The dependent variable was mean accuracy scores. Post hoc *t*-tests were carried out to determine whether there were significant differences between groups in mean accuracy at round one and round two, and to determine whether each group changed significantly in mean accuracy from round one to round two.

Hypothesis 2: hypothesized ego depletion effects for mean accuracy would be moderated by trait self-control. A multiple regression was conducted to test this hypothesis. Predictor variables included round one mean accuracy scores, condition, zero-centered trait self-control, and the interaction between condition and zero-centered trait self-control. The outcome

variable was round two mean accuracy scores. If a significant condition by trait self-control interaction were observed, post-hoc tests would be conducted. This would include plotting this interaction—as per recommendations by Aiken and West (1991) and Cohen and Cohen (1983)—and subsequently determining the exact point on the regression lines where the control and experimental groups differed in mean accuracy by employing the Johnson-Neyman technique (Johnson & Fay, 1950; Johnson & Neyman, 1936; Aiken & West, 1991). Rather than simply determining whether the slopes of the split-file regression lines differ significantly from zero—which does not properly assess how the focal predictor (in this case, condition) varies as a function of the moderating variable (trait self-control), especially when there are additional variables in the original regression (e.g., round one mean accuracy)—the Johnson-Neyman technique allows us to determine the exact value of trait self-control where significant differences between conditions emerge (Hayes & Matthes, 2009).

Hypothesis 3: hypothesized ego depletion effects for mean accuracy would be moderated by psychological resilience. A multiple regression was conducted to test this hypothesis. Predictor variables included round one mean accuracy scores, condition, zero-centered resilience scores, and the interaction between condition and zero-centered resilience. The outcome variable was round two mean accuracy scores. If a significant condition by resilience interaction were observed, post-hoc tests would be conducted. As described above, this would include plotting the interaction and determining the exact point on the regression lines where the control and experimental groups differed in mean accuracy by using the Johnson-Neyman technique.

Hypothesis 4: participants in the experimental condition would be less consistent in terms of accuracy in round two compared to participants in the control condition. A 2

(time) X 2 (condition) Repeated Measures ANOVA was conducted to test this hypothesis. The dependent variable was the standard deviation of accuracy scores. Post hoc *t*-tests were carried out to determine whether there were significant differences between groups in standard deviation of accuracy at round one and round two, and to determine whether each group changed significantly in standard deviation of accuracy from round one to round two.

Hypothesis 5: participants in the experimental condition would show slower overall reaction time in round two compared to participants in the control condition. A 2 (time) X 2 (condition) Repeated Measures ANOVA was conducted to test this hypothesis. The dependent variable was mean reaction time scores. Post hoc *t*-tests were carried out to determine whether there were significant differences between groups in mean reaction time at round one and round two, and to determine whether each group changed significantly in mean reaction time from round one to round two.

Hypothesis 6: hypothesized ego depletion effects for mean reaction time would be moderated by trait self-control. A multiple regression was conducted to test this hypothesis. Predictor variables included round one mean reaction time scores, condition, zero-centered trait self-control, and the interaction between condition and zero-centered trait self-control. The outcome variable was round two mean reaction time scores. If a significant condition by resilience interaction were observed, post-hoc tests would be conducted. As previously described, this would include plotting the interaction and determining the exact point on the regression lines where the control and experimental groups differed in mean reaction time by using the Johnson-Neyman technique.

Hypothesis 7: hypothesized ego depletion effects for mean reaction time would be moderated by psychological resilience. A multiple regression was conducted to test this

hypothesis. Predictor variables included round one mean reaction time scores, condition, zero-centered resilience scores, and the interaction between condition and zero-centered resilience. The outcome variable was round two mean reaction time scores. If a significant condition by resilience interaction were observed, post-hoc tests would be conducted. As previously described, this would include plotting the interaction and determining the exact point on the regression lines where the control and experimental groups differed in mean reaction time by using the Johnson-Neyman technique.

Hypothesis 8: participants in the experimental condition would be less consistent in terms of reaction time in round two compared to participants in the control condition. A 2 (time) X 2 (condition) Repeated Measures ANOVA was conducted to test this hypothesis. The dependent variable used was the standard deviation of reaction time scores. Post hoc *t*-tests were carried out to determine whether there were significant differences between groups in standard deviation of reaction time at round one and round two, and to determine whether each group changed significantly in standard deviation of reaction time from round one to round two.

Hypothesis 9: participants in the experimental condition would show greater myoelectrical activation of the biceps and triceps in round two compared to participants in the control condition. Two 2 (time) X 2 (condition) Repeated Measures ANOVAs were conducted to test this hypothesis. The first ANOVA used mean peak myoelectrical activation of the biceps as the dependent variable, while the second ANOVA used mean peak myoelectrical activation of the triceps as the dependent variable. Post hoc *t*-tests for both the biceps and triceps were carried out to determine whether there were significant differences between groups in mean peak myoelectrical activation at round one and round two, and to determine whether each group changed significantly in mean peak myoelectrical activation from round one to round two.

Results

Participant Characteristics and Preliminary Analyses

Means and standard deviations for all measures at baseline and post-manipulation were calculated and served as the descriptive statistics. Sixty-two participants (31 males and 31 females) took part in the study. The average participant age was 22.8 years ± 3.95. All participants indicated that they either never played darts before (n = 17), or that they only played recreationally (i.e., non-competitively) once per year (n = 35) or once every few months (n = 10). A series of one-way ANOVAs revealed that the experimental and control groups did not differ significantly in age, sex, dart-tossing experience, any of the manipulation checks (Table 1).

Hypothesis 1: Participants in the Experimental Condition Would Show Poorer Overall Accuracy in Round Two Compared to Participants in the Control Condition

The 2 (time) X 2 (condition) Repeated Measures ANOVA revealed no significant main effects for time, $F(1, 60) = 0.05$, $p = .820$, or condition, $F(1, 60) = 0.87$, $p = .354$. As hypothesized, there was a significant time X condition interaction, $F(1, 60) = 8.16$, $p = .006$. A post-hoc t test revealed that there was no significant difference in mean accuracy between conditions at round one, $t(60) = 0.18$, $p = .862$, Cohen's d = .05, but that the control group was significantly more accurate than the experimental group at round two $t(60) = -2.13$, $p = .038$, Cohen's d = .55. The control group's mean accuracy improved by 0.79 cm from round one to round two; a post-hoc t test revealed that this improvement approached significance, $t(30) = -1.86$, $p = .073$, Cohen's d = .22. The experimental group's mean accuracy declined by 0.93 cm; a post-hoc t test showed that this deterioration was significant, $t(30) = 2.18$, $p = .037$, Cohen's d = .37. For illustrative purposes, average shot-by-shot accuracy values for each condition are shown in Figure 1.

Hypothesis 2: Hypothesized Ego Depletion Effects for Mean Accuracy Would Be Moderated by Trait Self-Control

The multiple regression showed that the overall model was significant, $R^2 = .61$, adjusted $R^2 = .58$, $F(4, 57) = 22.06$, $p < .001$, in predicting round two accuracy scores (Table 3). A significant main effect emerged for round one mean accuracy, $p < .001$; for every one-centimeter increase in round one mean accuracy scores, there was a .63-centimeter increase in round two accuracy scores. A significant main effect also emerged for condition, $p = .001$, as participants in the control group showed better accuracy in round two. Scores of trait self-control did not significantly predict round two accuracy. A significant condition by trait self-control interaction, $p = .044$, was found, thus superceding the main effect observed for condition.

In accordance with recommendations given by Aiken and West (1991) and Cohen and Cohen (1983), three equations were calculated to plot the interaction between condition and trait self-control. To do so, the data file was first split by condition. A regression was then computed with round one mean accuracy and trait self-control as the predictor variables and round two mean accuracy as the outcome variable. Cohen and Cohen (1983) suggest computing values of the moderator variable to generate three simple regression equations: a) one standard deviation below the mean moderator score; b) the mean moderator score; and c) one standard deviation above the mean moderator score. These equations were computed for both the control and experimental group. The formula for these equations was: Y (round two mean accuracy) = *B* for constant + (*B* for round one mean accuracy X baseline mean accuracy) + (*B* for trait self-control X –1 standard deviation trait self-control score/mean trait self-control score/+1 standard deviation trait self-control score). The formulas for each condition thus looked as such:

Y (control group) = .406 + (.642 X 11.408) + (.063 X 38.357/45.484/52.611)

Y (experimental group) = 8.856 + (.612 X 11.253) + (-.081 X 36.547/44.032/51.518)

The resulting visual depiction of this moderation is given in figure 3. As shown, there was a negative slope for the experimental group and a positive slope for the control group.

The Johnson-Neyman technique (Johnson & Fay, 1950; Johnson & Neyman, 1936; Aiken & West, 1991) was then used to determine the point on the regression lines where the control and experimental groups differed in mean accuracy. Results showed that the region below the trait self-control score of 3.77 crossed the significance level, $p < .05$. The shaded area in figure 1 represents this region of significance. In other words, participants in the experimental condition were significantly less accurate in the second round of dart-tossing than participants in the control condition when they had a centered trait self-control score of 3.77 (approximately +0.5SD) or lower. Those with trait self-control scores higher than 3.77 were essentially unaffected by the experimental manipulation relative to the control condition.

Hypothesis 3: Hypothesized Ego Depletion Effects for Mean Accuracy Would Be Moderated by Psychological Resilience

The multiple regression showed that the overall model was significant, $R^2 = .59$, adjusted $R^2 = .58$, $F(4, 57) = 22.06$, $p < .001$, in predicting round two accuracy scores (Table 4). A significant main effect emerged for round one mean accuracy, $p < .001$; for every one-centimeter increase in round one accuracy, there was a .66-centimeter increase in round two accuracy. A significant main effect was also evident for condition, $p = .001$, such that participants in the control group showed better round two accuracy scores. Scores for resilience did not significantly predict round two accuracy, $p = .285$, and the interaction between condition and resilience was not significant, $p = .333$.

Hypothesis 4: Participants in the Experimental Condition Would Be Less Consistent in Terms of Accuracy in Round Two Compared to Participants in the Control Condition

The 2 (time) X 2 (condition) Repeated Measures ANOVA revealed a non-significant trend of a main effect for time, $F(1,60) = 2.81$, $p = .099$; there was not a significant main effect for condition, $F(1,60) = 0.40$, $p = .529$. There was a significant time X condition interaction, $F(1,60) = 8.97$, $p = .004$. A post-hoc *t* test revealed that there was no significant difference between conditions in consistency at round one, $t(60) = 1.13$, $p = .264$, Cohen's d = .29, but that the control group was significantly more consistent than the experimental group at round two, $t(60) = -2.41$, $p = .019$, Cohen's d = .62. The control group's consistency improved from round one to round two by 0.39 cm, while the experimental group's consistency deteriorated by 1.38 cm. Post-hoc *t* tests (two-tailed) showed that the improvement in the control group's standard deviation from round one to round two was not significant, $t(30) = -.81$, $p = .426$, Cohen's d = .17, while the deterioration in the experimental group's standard deviation was significant, $t(30) = 4.05$, $p < .001$, Cohen's d = .88.

Hypothesis 5: Participants in the Experimental Condition Would Show Slower Overall Reaction Time in Round Two Compared to Participants in the Control Condition

The 2 (time) X 2 (condition) Repeated Measures ANOVA revealed that there were no significant main effects for time, $F(1,60) = 0.39$, $p = .537$, or condition, $F(1,60) = 1.02$, $p = .318$. Contrary to hypothesis, the time X condition interaction was not significant, $F(1,60) = 0.01$, $p = .769$. Thus, ego depletion effects did not affect mean reaction times. For illustrative purposes, average shot-by-shot reaction time values for each condition are shown in Figure 2.

Hypothesis 6: Hypothesized Ego Depletion Effects for Mean Reaction Time Would Be Moderated by Trait Self-Control

A multiple regression revealed that the overall model was significant, $R^2 = .83$, adjusted $R^2 = .82$, $F(4, 57) = 69.27$, $p < .001$ (Table 5). However, only round one mean reaction time was a significant predictor of round two mean reaction time, $p < .001$; for every one-second increase in round one reaction time, there was a 1.07-second increase in round two reaction time. There was a non-significant trend towards an interaction between trait self-control and condition in predicting round two reaction time scores, $p = .106$.

Hypothesis 7: Hypothesized Ego Depletion Effects for Mean Reaction Time Would Be Moderated by Psychological Resilience

The multiple regression revealed that the overall model was significant, $R^2 = .82$, adjusted $R^2 = .81$, $F(4, 57) = 66.22$, $p < .001$ (Table 6). However, only round one mean reaction time was a significant predictor of round two mean reaction time, $p < .001$; for every one-second increase in round one reaction time, there was a 1.06-second increase in round two reaction time. There was no interaction between resilience and condition in predicting round two reaction time scores, $p = .445$.

Hypothesis 8: Participants in the Experimental Condition Would Be Less Consistent in Terms of Reaction Time in Round Two Compared to Participants in the Control Condition

The 2 (time) X 2 (condition) Repeated Measures ANOVA revealed a significant main effect for time, $F(1, 60) = 11.45$, $p = .001$, but not for condition, $F(1, 60) = 0.21$, $p = .664$. There was a significant time X condition interaction, $F(1, 60) = 3.87$, $p = .050$. A post-hoc *t* test showed that there were no significant differences between groups at round one, $t(60) = 0.63$, $p = .532$, Cohen's d = .16, or round two, $t(60) = -1.47$, $p = .148$, Cohen's d = .42. However, post-hoc *t*-tests revealed that the reaction time standard deviation for the control group decreased significantly from round one to round two (-0.09 seconds), $t(30) = -3.59$, $p = .001$, Cohen's d =

-.73. The experimental group's reaction time standard deviation did not change significantly (-0.02 seconds), $t(30) = -1.06$, $p = .297$, Cohen's d = .16.

Hypothesis 9: Participants in the Experimental Condition Would Show Greater Myoelectrical Activation of the Biceps and Triceps in Round Two Compared to Participants in the Control Condition

The 2 (time) X 2 (condition) Repeated Measures ANOVA for biceps revealed no significant main effects for time, $F(1, 57) = 0.22$, $p = .639$, or condition, $F(1, 57) = 1.21$, $p = .276$. The time X condition interaction was not significant, $F(1, 57) = 0.93$, $p = .339$. The 2 (time) X 2 (condition) Repeated Measures ANOVA for triceps revealed no main effect for time, $F(1, 56) = 0.64$, $p = .428$. There was a non-significant trend of a main effect for condition, $F(1, 56) = 2.89$, $p = .095$. Contrary to hypothesis, the time X condition interaction was not significant, $F(1, 56) = 0.65$, $p = .423$.

Post-Hoc Findings

Inspection of the data revealed several noteworthy findings of relevance to our hypotheses.

Participants' most and least accurate tosses. Although not hypothesized, we observed that most control group participants took their most accurate toss in the second round of tossing (69%) rather than the first round (31%). Therefore, a chi-square analysis was computed in which these observed frequencies for each round were compared against the expected frequencies of an equal chance of the most accurate toss occurring in either round (i.e., 50% and 50%). The results confirmed that this difference was significant, χ^2 (1) = 4.17; $p = .041$, and, thus, more control group participants executed their most accurate toss in round two rather than round one. However, this same effect did not occur for the experimental group; more experimental group

participants tended to take their most accurate toss in the first round of tossing (61%) than in the second round (39%), although, this difference was not significant, χ^2 (1) = 1.29; p = .25.

We then looked at participants' least accurate toss. Significantly more experimental group participants took their least accurate toss in the second round of tossing (84%) as opposed to the first round (16%), χ^2 (1) = 14.23; $p < .001$. While more control group participants tended to execute their least accurate shot in round one (54%) than in round two (46%), this difference was not significant, χ^2 (1) = 0.29; p = .590.

Tosses taken on false cue light. We also noted the number of tosses that participants took when a non-cue light flashed (i.e., the red or yellow light in round one and the green or yellow light in round two). There were no incorrect tosses by any participants in either condition in the first round of tossing. However, there were six incorrect tosses taken by the experimental group (all by different participants) in the second round of tossing compared to zero incorrect tosses taken by the control group. A chi-square analysis was computed and revealed that this difference between groups was significant, χ^2 (1) = 6.64; p = .010.

Discussion

The purpose of this study was to determine if ego depletion effects occur in the performance of a dart-tossing task. Specifically, we sought to determine whether depleted self-regulation affected participants' accuracy, reaction time, and myoelectrical activation of the biceps and triceps muscles. To the best of our knowledge, this is the first study to test self-regulatory depletion effects on skill-based task performance.

Regarding accuracy, we found evidence for the detrimental effects of ego depletion. Following the experimental manipulation, the experimental group demonstrated poorer mean accuracy than the control group. While control group participants' overall accuracy tended to

improve from round one to round two, experimental group participants were significantly less accurate at round two compared to round one. Thus, the effects of depleted self-regulation seemed to not only prevent experimental group participants from obtaining improvements in overall accuracy—as was the trend for the control group—but it actually resulted in *deteriorations* in their overall accuracy. In addition, the experimental group's standard deviation for accuracy was significantly greater than the control group's following the experimental manipulation. While the experimental group's standard deviation increased significantly from round one to round two, no such increases occurred for the control group. Thus, depleted self-regulation seems to result in poorer consistency in terms of accuracy. In regards to reaction time, our hypotheses regarding the effects of ego depletion were sparsely supported, as there were no significant differences between groups in mean reaction time or consistency following the experimental manipulation. However, it was shown that the standard deviation for reaction time for the control group decreased significantly from round one to round two; this was not the case for the experimental group. In other words, while control group participants' reaction time consistency improved from round one to round two, the experimental manipulation seemed to prevent experimental group participants from becoming more consistent.

We also noted, post hoc, that significantly more control group participants took their most accurate toss in the second round of tossing rather than the first round. This result makes sense, as improvements in accuracy on this task should occur for participants due to practice effects, culminating with a single, highly successful toss. However, this improvement between rounds did not occur for the experimental group. Rather, more experimental group participants executed their most accurate toss in the first round of tossing than in the second round. While this difference between rounds was not significant for the experimental group, it is interesting to

note that the effects of depleted self-regulation seemed to preclude experimental group participants from obtaining their most accurate toss during the second round, as was the case for the control group. In addition, it was shown that significantly more experimental group participants took their least accurate toss in the second round of tossing than in the first. Thus, it not only seems that the effects of depleted self-regulation can prevent individuals from executing their best performance (in terms of accuracy on one toss), but it can also result in individuals experiencing their worst performance. This is another important finding as there are certainly instances during a sports competition when a single performance can carry tremendous weight in determining the outcome of that competition.

The findings outlined above demonstrate that depleting individuals' self-regulatory resources is not only detrimental for *endurance-based* physical tasks (e.g., Bray et al., 2008; Muraven et al., 1998; Muraven & Shmueli, 2006; Vohs et al., 2005) but also seems to affect performance for *skill-based* physical tasks, particularly those that require accuracy. As this is the first study to test these effects on skilled task performances, there are numerous potential explanations for our findings. Our a priori hypothesis was that myoelectrical activation would explain—at least in part—why depleting individuals' self-regulatory resources results in poorer performance on the dart-tossing task. However, there were no significant between-group differences in muscle activation at any point during the study. Therefore, myoelectrical activation does not seem to be the explanatory mechanism of ego depletion's effects on this particular skill-based task. However, muscle activation may play a role in affecting performance on other skill-based tasks. We did find that the peak EMG amplitude of the biceps increased from round one to round two by 2.2% for the experimental group (Cohen's d = .13); in contrast, there was a mere 0.3% increase for the control group (Cohen's d = .02). Likewise, there was a

4.2% increase in the peak EMG amplitude of the triceps from round one to round two for the experimental group (Cohen's d = .15) compared to just a 1.6% increase for the control group (Cohen's d = .07).

The fact that these differences were not significant may be due to the type of task we chose. That is, compared to some other skill-based tasks, such as throwing a baseball as hard as possible or taking a slapshot in hockey, dart tossing does not require as much muscular activation. Myoelectrical activation may only have a significant impact on the performance of these types of tasks because there is a much greater demand on the muscles. Indeed, Bray et al. (2008) found between-group differences in muscle activation, post-depletion, on an isometric handgrip squeeze, a task that requires relatively more muscular activation than dart tossing. In addition, an endurance-based task such as an isometric handgrip squeeze and skill-based tasks such as near-maximum-force baseball throws or hockey slapshots are more prone to muscular fatigue compared to tossing a dart. Therefore, in relation to ego depletion, muscle activation may only have a significant impact on performance of endurance- and skill-based tasks that (a) require a high amount of muscle activity and/or (b) are prone to fatigue. Had we tested the effects of ego depletion on this type of a skill-based task, we may have found significant differences between groups, post-manipulation. However, at present, muscle activation does not seem to be the explanatory mechanism of ego depletion for a skill-based physical task that requires minimal muscular exertion. Rather, there are likely other explanations for why depleted self-regulation impaired performance on the dart-tossing task.

Perhaps a more probable explanation is that depleted self-regulation impairs individuals' executive functioning (Banfield, Wyland, Macrae, Munte, & Heatherton, 2004; Wagner & Heatherton, 2011). Depleting individuals' self-regulatory capacities results in poorer

performances on numerous tasks, such as maintaining an isometric handgrip squeeze (Bray et al., 2008; Muraven et al., 1998; Muraven & Shmueli, 2006; Vohs, Baumeister, & Ciarocco, 2005), and this seems to be due to impairments in executive functioning (Wagner & Heatherton, 2011). That is, depleting participants' self-regulatory resources may result in a poorer ability for them to inhibit their natural desire to quit this physically fatiguing and uncomfortable task, an activity under executive control. In addition, much research has shown that damage to the prefrontal cortex often results in the inability to carry out many other executive functioning activities, including cognitive decision making, planning and executing skilled motor actions, and regulating attention (Wagner & Heatherton, 2011)—each of these were involved in performing the dart-tossing task. While we certainly are not insinuating that self-regulatory depletion is nearly as significant as prefrontal cortex damage in determining an individual's ability (or *inability*) to complete these behaviours, it may be that individuals have a *decreased* ability to complete tasks that are under executive control when they are depleted compared to when they are not depleted. In line with past research, it is possible that depleted participants in the current study had a poorer ability to carry out these executive control activities compared to non-depleted participants.

One particular component of executive functioning, cognitive decision-making (including response inhibition and response initiation; Banfield et al., 2004) likely played an important role in successfully completing the dart-tossing task. Recall that participants were instructed to toss when the cue light flashed (initiation) and to not toss when the non-cue lights flashed (inhibition). As reaction time was one of the measures of performance, it was important for participants to make quick yet appropriate decisions at each light flash. An inability to do so efficiently could result in slow reaction time or tossing on a non-cue light. Along similar lines of

previous research on response inhibition (e.g., Baumeister et al., 1998; Muraven et al., 1998), we contend that depleting participants' self-regulation likely affected their decision-making abilities in completing this task. While the experimental manipulation did not seem to affect participants' overall abilities to react quickly, there was some evidence to suggest that participants in the experimental group did not always make the appropriate decision. Although this was difficult to quantify in our study (as our main measures were accuracy and reaction time), the finding that experimental group participants had significantly more false tosses (six) in the post-manipulation round of tossing than the control group (zero) supports previous findings (e.g., Baumeister et al., 1998; Muraven et al., 1998) that decision making (particularly, response inhibition) is impaired when individuals are depleted.

The prefrontal cortex also plays an important role in planning and executing controlled and effective motor movements (Sage, 1984; Barbas & Pandya, 1987; Petrides & Pandya, 1999). Damage to this area has been shown to result in decrements in individuals' abilities to plan and carry out novel motor actions (Miller & Cohen, 2001; Pascual-Leone, Wasserman, Grafman, & Hallett, 1996). It is highly unlikely that any of the participants had previously engaged in dart-tossing in the manner in which it was laid out in the current study (i.e., to aim for the bulls-eye on each toss and trying to have as quick of a reaction time as possible upon seeing a cue light flash). As such, participants needed to develop and execute a strategy for tossing in a manner that resulted in a quick reaction time and accurate toss. There are several factors that may have played a role in developing this strategy and participants' strategies may have been different from each other (e.g., upon seeing the cue light, some individuals cocked their throwing arm back slightly and then extended the arm forward, while others chose to simply extend their arm forward without initially bringing it back). However, the overall goal for each participant would

be the same: to develop an effective motor plan that results in accurate tosses that were tossed as quickly as possible upon seeing the cue light. To do so, participants needed to take in all of the factors about task-relevant stimuli and learn what strategy was most effective based on their performance on each toss (Sage, 1984). Depleting experimental group participants' self-regulatory resources would impair their executive functioning abilities and, therefore, result in a poorer ability for these participants to develop effective strategies compared to control group participants. In turn, less effective strategies would have contributed to the experimental group performing poorer than the control group in terms of overall accuracy.

Developing effective motor strategies may also be part of the reason why there were differences from round one to round two in consistency for accuracy and reaction time. As mentioned, the experimental group's consistency for accuracy deteriorated significantly from round one to round two, while the control group's did not. In addition, the control group's consistency for reaction time improved significantly from round one to round two, while the experimental group's did not. Put another way, the experimental group's consistency either decreased (accuracy) or stayed the same (reaction time), while the control group's consistency either improved (reaction time) or stayed the same (accuracy). It may be that the control group participants were able to develop and maintain an effective motor plan (thus resulting in more consistent performances or, at the very least, preventing less consistent performances from emerging). Conversely, experimental group participants may have been unable to maintain as effective of a motor strategy as control group participants due to the depletion of their self-regulatory resources negatively affecting their executive functioning. Thus, the lack of consistency in their performances may indicate that depleted participants were continually modifying their motor strategies. This assertion aligns with previous research, which has shown

that improvements in procedural motor learning (i.e., the acquisition of new knowledge of a motor task by repeatedly performing the task) and execution can be impeded by disrupting areas of the prefrontal cortex (Pascual-Leone et al., 1996).

Attention—another key component of executive functioning (Banfield et al., 2004)—would have also been involved in successfully completing the dart-tossing task. One's capacity to attend to and focus on sensory information that is relevant to achieving one's goal while ignoring irrelevant cues that are detrimental to performance is critical for successful task performance (Pashler & Johnston, 1998; Posner, 1980). Attentional control also requires self-regulation (Wagner & Heatherton, 2010) and, not surprisingly, previous research has shown that the depletion of one's self-regulatory resources can result in a poorer ability to maintain attention (Rothbart, Ellis, & Posner, 2011; Sayette & Griffin, 2011). In the current study, participants needed to be vigilant to the visual information provided by the lightbox above the dartboard so that they could toss at the correct time (i.e., when the cue light flashed). At the same time, they needed to maintain a certain amount of visual focus on their target—the bulls-eye of the dartboard. They also needed to take in proprioceptive information, such as identifying the orientation of their body in relation to the dartboard, their posture and position of their limbs (i.e., their stance and the way they hold the dart), and bodily movements (i.e., the manner in which they aim and toss). Consistent with previous findings (Rothbart et al., 2011), it may be that the depletion of experimental participants' self-regulatory reserve resulted in a poorer ability for them to focus their attention on the above-mentioned stimuli appropriately and efficiently. In turn, this would have contributed to poorer task performance for depleted participants.

The amount of attention that needed to be devoted to the task may also help explain why depleted self-regulation resulted in round two decrements in accuracy but not reaction time. It is

possible that trying to be accurate on this task required more attentional resources than trying to react quickly. That is, to be accurate, participants needed to attend to more features of the task, such as their stance, how they held the dart, how they aimed the dart, and how much force they used to toss the dart towards the dartboard; at the same time, they needed to pay attention to the lights that were being flashed to avoid a false toss. Hence, executive functioning would be highly involved in this aspect of the task. Therefore, if an individual's executive functioning is impaired due to a depletion of his self-regulatory resources, his accuracy on a task is likely to suffer. On the contrary, the reaction time aspect of this task would not require as much attention as accuracy to be completed effectively. Participants simply had to pay attention to the lights that were being flashed (again, to avoid a false toss) and move their arm in some manner upon seeing the cue light flash. Therefore, executive functioning may not be as involved in reaction time for this task as accuracy. As such, impairments in executive functioning due to a depletion of one's self-regulatory resources may be less likely to affect reaction time.

Expanding on the reasons why there were ego depletion effects for overall accuracy but not overall reaction time, another possibility is that participants became more concerned with being highly accurate than on reacting quickly. The goal in regulation dart tossing is to be as accurate as possible and there is no measure of reaction time. Although the experimenter instructed participants to react as quickly as possible (in addition to being as accurate as possible), the principal goal of being accurate in regulation dart tossing may have carried over to this experiment for those participants who had previously played darts. Also, participants were provided with more feedback in regards to accuracy than they were for reaction time. That is, after participants completed each toss, they were able to see the exact result of their toss in terms of accuracy (i.e., where the dart landed on the dartboard). By contrast, they were not able to see

the exact results of their toss in terms of reaction time—the experimenter was unable to give participants their exact reaction time score for each toss, as these scores were not calculated until after the experiment was completed. Moreover, after a very accurate toss (e.g., a bulls-eye or close to it) many participants said things such as "that was a good toss!" Or, when there was a highly inaccurate toss (e.g., the dart missed the board completely), many participants reacted negatively by saying things such as "that was awful!" However, no participants mentioned how good or poor they felt their most recent toss was in terms of reaction time. These reasons may suggest that participants had inadvertently become more focused on the goal of being accurate and less concerned with reacting quickly. As such, trying to be accurate may have required and consumed more self-regulatory resources—and would, therefore, be more prone to performance decrements in situations when individuals' resources are depleted—than reacting quickly. If this were the case, this may explain why ego depletion effects only occurred for mean accuracy and not mean reaction time, as depleted self-regulation is said to impede the performance of goal-directed behaviours. In hindsight, it would have been valuable to assess whether participants had focused just as much on reaction time as they did accuracy.

Our results regarding trait self-control as a potential moderator of ego depletion are also noteworthy. We found that experimental group participants with higher trait self-control were less likely to show deteriorations in their mean accuracy, post-manipulation, compared to experimental group participants who scored lower on trait self-control. Between the experimental and control conditions, the deleterious effects of depleted self-regulation were most pronounced for participants who scored below average (i.e., -1SD) on the trait self-control scale, decreased for participants of average trait self-control, and were eliminated for participants who scored above average (+0.5SD and higher) on the trait self-control scale. This provides evidence

that individuals with a greater capacity to self-regulate may be less prone to the deleterious effects of depleted self-regulation in completing a skill-based task compared to those with lower trait self-control. This is an important contribution to the self-regulation literature, as Hagger et al. (2010a) have recommended that researchers consider the influence of trait self-control in their tests of ego depletion. Our results provide further evidence that individuals' trait self-control may indeed have a significant impact on determining whether depleted self-regulation impairs task performance. This finding also provides some indirect evidence that increasing individuals' self-regulatory capacities may result in better task performance, post-depletion.

By contrast, our hypotheses regarding psychological resilience were not supported, as resilience did not significantly moderate overall performance in terms of accuracy or reaction time. Therefore, resilience does not seem to play a role in how well individuals perform on a task after they have been depleted. In hindsight, this finding may not be surprising. As mentioned, resilience refers to an individual's ability to bounce back from stress or adversity. It is not a trait specific to executive functioning or self-regulation (as opposed to trait self-control, for example, which is essentially exclusive to self-regulation). In other words, resilience is not an individual's ability to bounce back from a *depleting* situation or, in terms of the self-regulatory resource, the ability to refuel one's resource.

Implications

The results of this study have some important theoretical and practical implications. From a theoretical perspective, as previously noted, this study has shown that—in addition to many other spheres within the social sciences—the tenets of the limited strength model extend to the performance of skill-based tasks. In particular, we have demonstrated that the depletion of individuals' self-regulatory resources can impair subsequent performance—especially in regards

to accuracy—on a skilled physical task that requires self-regulation. As there has been very little research on self-regulation in sport, this is an important contribution as it demonstrates the viability of using the limited strength model to understand self-regulatory failures in the sport domain. As a result, this provides a basis for future researchers to use the limited strength model to conduct much-needed research on self-regulation in sport.

We have also advanced theory by ruling out muscle activation as the primary mechanism for ego depletion effects in low-exertion, skilled tasks. As noted, there has been very little previous research analyzing mechanisms. Our results suggest that other mechanisms might explain the effects such as cognitive decision making, attention, and planning and executing effective motor movements. This information provides direction for investigators' choice of potential mediators to be tested in future experiments.

We also identified trait self-control as a moderator of the ego depletion effects for performing a skill-based task that requires self-regulation. Therefore, it may be considered vital for researchers to include assessments of trait self-regulation—such as Tangney et al's (2004) trait self-control scale—in ego depletion experiments. By contrast, our results suggest that psychological resilience is not a moderator of the ego-depletion effects in skilled task performance. Therefore, while research has shown that resilience is an important component of optimal performance in sports (e.g., Gould et al., 2002; Gucciardi et al., 2011), this trait does not seem to be an important variable to consider when assessing the effects of depleted self-regulation on skilled performance. Identifying potential mediators and moderators of ego depletion effects—as we have done here—is important to further develop and refine the limited strength model. That is, researchers would be better aware of why these effects occur (i.e., mediators) and what may modify them (i.e., moderators). In addition, as mentioned by Hagger et

al. (2010a), identifying moderators would help explain why inconsistencies sometimes occur in examinations of self-regulation (e.g., Stillman et al., 2009; Wright, Junious, Neal, Avello, Graham, Hermann, et al., 2007; Wright, Stewart, & Barnett, 2008).

From a practical perspective, our results suggest that self-regulatory depletion can impact performance on skill-based tasks that require self-regulation. As our sample mainly consisted of inexperienced participants performing a novel task, it seems that individuals who are developing a skill (e.g., a new hockey player learning how to shoot, a novice pianist learning a new piece, etc.) are susceptible to self-regulatory depletion effects. Whether these effects generalize to more experienced performers/athletes or other tasks remains to be seen. Nevertheless, these results may be important for sports teams and athletes to consider. Athletes often claim that their sport is "a game of inches," meaning that even small defects in task execution—especially those that require accuracy—could carry great weight in determining the outcome of a situation or the entire game itself. For example, if a basketball player's shot at the last second of a game in which her team is trailing is off by just a few centimeters, then a loss for her team would result. Our results suggest that the amount of self-regulatory resources that individuals have may influence their performance on these types of skilled tasks. With further research, our initial evidence may evolve into very important implications within sport psychology.

Limitations

Despite some important findings in this study, there are some limitations worth noting. For instance, we have a limited ability to generalize our results to other skilled, sports tasks and to athletic populations. In this study, we chose to use dart tossing as our skill-based task. While it seemed to be an appropriate task for testing our hypotheses, we recognize that we are unable to assert conclusively that the findings of this study would carry over to other skill-based physical

tasks. Dart tossing is a rather simple task with a fixed target that requires few muscles to be executed compared to other sports tasks. Therefore, it would be premature to suggest that such ego depletion effects occur for more advanced or complicated skills, such as hockey shooting, football throwing, or goaltending in soccer (i.e., complex skills that require more muscles and gross movements to complete). Second, our sample only consisted of non-elite dart-tossers. It is, thus, too early to claim that the effects of depleted self-regulation generalize to more competitive populations (e.g., professional dart-tossers).

The time at which participants completed the trait self-control and resilience questionnaires may also be considered a limitation. As described in the **Procedure** section, participants filled out these questionnaires immediately after the second round of dart tossing. It could be argued that individuals' performance in this second round influenced their answers on these questionnaires. For instance, if there were times when a participant had a very inaccurate toss followed by a highly accurate toss, this may have primed him to report that he is more resilient than is actually the case. Had he not completed the resilience questionnaire so soon after this second round, his answers may have been more reflective of how truly resilient he is. Likewise, if a participant had made a false toss or flinched numerous times when seeing a non-cue light flash, her answers on the trait self-control questionnaire may have been influenced and reflect poorer self-control than is actually the case. Thus, it may have been beneficial to have participants complete these questionnaires at another time, such as prior to when the experiment was conducted.

It is also recognized that the peak EMG amplitude for the triceps was quite high, with the group mean activation for each condition over 50% of individuals' maximum triceps activation. It is highly unlikely that executing a dart toss truly required this much muscle activation. It is

probable that these inordinate values arose due to inadequate measurement of participants' maximum voluntary contractions. As described in the **Procedure** section, participants placed their arm at their side, with a 90-degree bend at the elbow and their palm facing inwards (i.e., medially); they then extended their triceps downwards with as much force as possible (as if they were completing a triceps extension), while the experimenter provided appropriate resistance. Although the experimenter reinforced to the participants that they try to only push down using their triceps, some may have used more of their other muscles such as their deltoids and less of their triceps. As such, the value of this MVC may have been less than participants' true maximum for their triceps. As a result, when they completed the dart-tossing task—more specifically, the extension of their triceps—the peak EMG amplitude values for the triceps would have been inaccurately high. It is important that MVCs are measured correctly to obtain accurate EMG data. Future researchers should be mindful of this to prevent similar potential drawbacks. Perhaps for this task, a better method of measuring MVCs would have been to have participants simulate a dart toss while the experimenter provided resistance to the extension component of this simulated toss.

Another potential limitation is that experimenter bias may have impacted the results of this study, as the experimenter conducting the study was aware of the hypotheses. This was considered beforehand and numerous steps were taken to eliminate (or at least substantially reduce) any potential issues. For instance, accuracy was specifically defined as the distance from the center of the bulls-eye to the point where the dart was lodged. If there would have been an arbitrary—rather than specific—definition of distance, the experimenter may have been more or less liberal in his measurements depending on which condition the participant was in (e.g., measuring from the dart to the near edge of the bulls-eye for a participant in the control

condition, which would reduce the distance and/or measuring to the far edge of the bulls-eye for a participant in the experimental condition). In addition, there was a script for the entire experimental trial, which was the same for both the control and experimental conditions. The experimenter was mindful to only say things outlined in the script as best as he could and avoid providing praise or encouragement for some participants but not others. Nonetheless, it would have been beneficial to ensure the experimenter did not influence the results and remained blind to condition assignment perhaps by employing a second or third experimenter to conduct part of the experiment. This may have included having a second experimenter who was blind to condition assignment measure accuracy and a third experimenter conduct the Stroop task. Another possible method could have been to have participants complete an electronic version of the Stroop task on a laptop with the experimenter being unable to see this task being completed.

Future Directions

To address the limited generalizability of our results, it would be valuable for researchers to conduct similar experiments on other skill-based sports tasks to examine whether depleted self-regulation results in performance decrements in sports. Future research should also assess both elite and non-elite athletes. Elite athletes are more likely to display automaticity in the execution of their skills compared to recreational athletes (e.g., Leavitt, 1979; Smith & Chamberlin, 1992; Weidenbeck, 1985). That is, elite athletes can carry out their skill with little conscious control—this skill, thus, appears to be "automatic" in comparison to beginner athletes whose skill execution appears very effortful and requires more conscious control. Therefore, it may be that elite athletes are less prone to the effects of self-regulatory depletion, as attention seems to play a role in skillful task performance. Conversely, research has also shown that there are times when even elite athletes experience "attention-induced disruptions" (such as in high

pressure, "clutch" situations), which results in the athlete executing their skill with more conscious effort—this often results in performance decrements (Beilock, Carr, MacMahon, & Starkes, 2007). Thus, it may be that depleted self-regulation only affects performance in certain situations (e.g., clutch situations) among elite athletes. These questions warrant further investigation.

It may also prove beneficial for future research to assess the efficacy (and, later, the effectiveness) of a self-regulatory training program for improving performance on skill-based tasks that require self-regulation. As has been previously discussed, engaging in self-regulation depletes individuals of their self-regulatory resources due to the limited nature of this resource. However, in the long term, the strength model of self-regulation suggests that one's self-regulatory strength can be increased through practice. Analogously, performing a resistance exercise with a specific muscle limits individuals' abilities to perform a similar exercise that requires the use of that muscle; over time, however, a resistance-training program will strengthen the muscle and the individual will be better able to carry out exercises with this muscle (e.g., performing more repetitions or using a higher weight).

There is some initial evidence to suggest that practising self-control may help increase individuals' self-regulatory strength and, thus, make them better able to carry out behaviours that require self-regulation when they are depleted (Hagger et al., 2010a). For instance, a study by Muraven (2010) found that smokers who practiced self-control for two weeks remained abstinent for longer when they tried quitting compared to those who did not initially practice self-control. As suggested by the author—and consistent with the strength model—it seems that the observed differences between groups in abstinence was a result of experimental group participants increasing their self-regulatory strength by practising self-control. Therefore, it may also be that

increasing one's self-regulatory strength could prevent deleterious performances on skill-based physical tasks that require self-regulation when one is depleted. Numerous studies suggest that psychological skills training (e.g., visualization, positive self-talk, controlled breathing, etc.) can improve athletic performance (Behncke, 2004). If efficacy and effectiveness trials of practising self-regulation result in participants being less prone to the negative effects of ego depletion, it may be valuable for athletes to incorporate this type of training into their psychological skills training programs.

Future research should also test for the explanatory mechanisms underlying ego depletion effects. While it is clear from considerable experimental evidence that depleting individuals' self-regulatory capacities generally results in poorer performance on a second task that also requires self-regulatory resources, there is limited evidence that explains why this occurs. This should be considered an important next step in self-regulation research. This may include assessing psychophysiological influences (e.g., further tests of muscle activation when completing endurance-based tasks that require self-regulation), incorporating neuroimaging techniques (e.g., using fMRI scans to assess which areas of the brain—such as the prefrontal cortex—are involved in executing a self-regulatory task and determine whether activity in these areas change as a result of self-regulatory depletion), and developing and testing novel hypotheses of mediators. By digging deeper into these causal explanations, researchers would provide a more complete and better-understood model of self-regulation.

Conclusion

The results of the current study provide a novel contribution to the literature of self-regulation. In addition to previous research, which has demonstrated the effects of ego depletion on endurance-based physical tasks, we have provided initial evidence that these effects also

occur in the execution of skill-based tasks. This opens up a new and potentially very important line of research within the areas of ego depletion and sport psychology.

References

Aiken, L., & West, S. (1991). *Multiple regression: Testing and interpreting interactions.* Newbury Park, CA: Sage.

Banfield, J. F., Wyland, C. L., Macrae, C. N., Munte, T. F., & Heatherton, T. F. (2004). The cognitive neuroscience of self-regulation. In R. F. Baumeister & K. D. Vohs (Eds.), *Handbook of Self-Regulation: Research, Theory, and Applications* (pp. 62-83).

Barbas, H., & Pandya, D. N. (1987). Architecture and frontal cortical connections of the premotor cortex (Area 6) in the rhesus monkey. *Journal of Comparative Neurology, 256*, 211-228.

Basmajian, J. V. & De Luca, C. J. (1985). *Muscles alive: their functions revealed by electromyography*. Baltimore: Williams & Wilkins.

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., 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*. San Diego: 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., & Showers, C. J. (1986). A review of paradoxical effects: Choking under pressure in sports and mental tests. *European Journal of Social Psychology, 16*, 361-383.

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science, 16*, 351-355.

Behncke, L. (2004). Mental skills training for sports: A brief review. *Athletic Insight, 6*, 1-19.

Beilock, S. L., & Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied, 8,* 6-16.

Bembenutty, H. & Karabenick, S. A. (1998). Academic delay of gratification. *Learning and Individual Differences, 10*, 329-346.

Borg, G. A. V. (1998). *Borg's ratings of perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

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

Carlsson, A. M. (1983). Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. *Pain, 16*, 87-101.

Cohen, A., Ivry, R. I., & Keele, S. W. (1990). Attention and structure sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 17-30.

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

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlational analyses for the behavioral sciences* (1st ed.). Hillsdale, NJ: Lawrence Erlbaum.

Connor, K. M., & Davidson, J. R. T. (2003). Development of a new resilience scale: the Connor-Davidson resilience scale (CD-RISC). *Depression and Anxiety, 18*, 76-82.

Cooke, A., Kavussanu, M., McIntyre, D., & Ring, C. (2010). Psychological, muscular and kinematic factors mediate performance under pressure.

Dishman, R. K., Ickes, W., & Morgan, W. P. (1980). Self-motivation and adherence to habitual physical activity. *Journal of Applied Social Psychology, 10,* 115-132.

Dvorak, R. D., & Simons, J. S. (2009). Moderation of resource depletion in the self-control strength model: Differing effects of two modes of self-control. *Personality and Social Psychology Bulletin, 25*, 572-583.

Finkel, E. J., & Campbell, W. K. (2001). Self-control and accommodation in close relationships: an interdependent analysis. *Journal of Personality and Social Psychology, 81*, 263-277.

Funder, D. C., Block, J. H., & Block, J. (1983). Delay of gratification: Some longitudinal personality correlates. *Journal of Personality and Social Psychology, 44*, 1198-1213.

Funder, D. C. & Block, J. (1989). The role of ego-control, ego-resiliency, and IQ in delay of gratification in adolescence. *Journal of Personality and Social Psychology, 57*, 1041-1050.

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

Gailliot, M. T., Baumeister, R. F., DeWall, C. N., Maner, J. K., Plant, A., Tice, D. M., … 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.

Gailliot, M. T., Scheimel, B. J., & Maner, J. K. (2007). Differentiating the effects of self-control and self-esteem on reactions to mortality salience. *Journal of Experimental Social Psychology, 43*, 894-901.

Galli, N., & Vealey, R. S. (2008). "Bouncing back" from adversity: athletes' experiences of resilience. *The Sport Psychologist, 22*, 316-335.

Gould, D., Dieffenbach, K., & Moffett, A. (2002). Psychological characteristics and their development in Olympic champions. *Journal of Applied Sport Psychology, 14*, 172-204.

Gucciardi, D. F., Jackson, B., Coulter, T. J., & Mallett, C. J. (2011). The Connor-Davidson resilience scale (CD-RISC): dimensionality and age-related measurement invariance with Australian cricketers. *Psychology of Sport and Exercise, 12*, 1-11.

Haff, G. G., Lehmkuhl, M. J., McCoy, L. B., & Stone, M. H. (2003). Carbohydrate supplementation and resistance training. *Journal of Strength and Conditioning Research, 17*, 187-196.

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. (2010a). Ego depletion and the strength model of self-control: a meta-analysis. *Psychological Bulletin, 136*, 495-525.

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. (2010b). Self-regulation and self-control in exercise: the strength-energy model. *International Review of Sport and Exercise Psychology, 3*, 62-86.

Hall, P. A., Fong, G. T., Epp, L. J., & Elias, L. J. (2008). Executive function moderates the intention-behaviour link for physical activity and dietary behavior. *Psychology & Health, 23,* 309-326.

Hatzigeorgiadis, A., Theodorakis, Y., & Zourbanos, N. (2004). Self-talk in the swimming pool: The effects of self-talk on thought content and performance on water-polo tasks. *Journal of Applied Sport Psychology, 16*, 138-150.

Hayes, A. F. & Matthes, J. (2009). Computational procedures for probing interactions in OLS and logistic regression: SPSS and SAS implementations. *Behavior Research Methods, 41*, 924-936.

Hodges, P. W., & Bui, B. H. (1996). A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroencephalography & Clinical Neurophysiology, 101*, 511-519.

Inzlicht, M., & Gutsell, J. N. (2007). Running on empty: Neural signals for self-control failure. *Psychological Science, 18*, 933-937.

Johnson, P. O., & Fay, L. C. (1950). The Johnson-Neyman technique, its theory and application. *Psychometrika, 15*, 349-367.

Johnson, P. O., & Neyman, J. (1936). Tests of certain linear hypotheses and their applications to some educational problems. *Statistical Research Memoirs, 1*, 57-93.

Jordet, G. (2008). Why do English players fail in soccer penalty shootouts? A study of team status, self-regulation, and choking under pressure. *Journal of Sports Sciences, 27,* 97-106.

Larsby, B., Hällgren, M., Lyxell, B., & Arlinger, S. (2005). Cognitive performance and perceived effort in speech processing tasks: Effects of different noise backgrounds in normal-hearing and hearing-impaired subjects. *International Journal of Audiology, 44*, 131-134.

Larsson, S., Larsson, R., Zhang, Q., Cai, H., & Oberg, P A. (1995). Effects of psychophysiological stress on trapezius muscles blood flow and electromyography during static load. *European Journal of Applied Physiology, 71*, 493-498.

Lazarus, R. S. (2000). How emotions influence performance in competitive sports. *The Sport Psychologist, 14*, 229-252.

Leavitt, J. (1979). Cognitive demands of skating and stick handling in ice hockey. *Canadian Journal of Applied Sport Sciences, 4*, 46-55.

Lee, K. A., Hicks, G., Nino-Murcia, G. (1991). Validity and reliability of a scale to assess fatigue. *Psychiatry Research, 36*, 291-298.

Marsh, H. W., Gerlach, E., Trautwein, U., Ludtke, O., & Brettschneider, W. (2007). Longitudinal study of preadolescent sport self-concept and performance: reciprocal effects and causal ordering. *Child Development, 78*, 1640-1656.

Martin Ginis, K. A., & Bray, S. R. (2010). Application of the limited strength model of self-regulation to understanding exercise effort, planning, and adherence. *Psychology & Health, 25*, 1-14.

Martin-Krumm, C. P., Sarrazin, P. G., Peterson, C., & Famose, J. P. (2003). Explanatory style and resilience after sports failure. *Personality and Individual Differences, 35*, 1685-1695.

Masten, A. S. (2009). Ordinary magic: lessons from research on resilience in human development. *Education Canada, 49*, 28-32.

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

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Mummery, W. K., Schofield, G., & Perry, C. (2004). Bouncing back: the role of coping style, social support and self-concept in resilience of sport performance. *Athletic Insight, 6*, 1-18.

Muraven, M. (2010). Building self-control strength: Practicing self-control leads to improved self-control performance. *Journal of Experimental Social Psychology, 46*, 465-468.

Muraven, M., Baumeister, R. F., & Tice, D. M. (1999). Longitudinal improvement of self-regulation through practice: building self-control strength. *Journal of Social Psychology, 139*, 446-457.

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

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as limited resource: regulatory depletion patterns. *Journal of Personality and Social Psychology, 74*, 774-779.

Official rules of darts. *Darts Info World.* Retrieved April 18, 2011 from http://dartsinfoworld.com/darts-rules/.

Pascual-Leone, A., Wassermann, E. M., Grafman, J., & Hallett, M. (1996). The role of the dorsolateral prefrontal cortex in implicit procedural learning. *Experimental Brain Research, 107*, 479-485.

Pashler, H., & Johnston, J. C. (1998). Attentional limitations in dual-task performance. In H. Pashler (Ed.), *Attention* (pp. 155-189). East Sussex: Psychology Press.

Petrides, M., & Pandya, D. N. (1999). Dorsolateral prefrontal cortex: Comparative cytoarchitectonic analysis in the human and the macaque brain and corticocortical connection patterns. *European Journal of Neuroscience, 11*, 1011-1036.

Podlog, L., & Eklund, R. C. (2006). A longitudinal investigation of competitive athletes' return to sport following serious injury. *Journal of Applied Sport Psychology, 18*, 44-68.

Podlog, L., & Eklund, R. C. (2009). High level athletes' perceptions of success in returning to sport following injury. *Psychology of Sport and Exercise, 10*, 535-544.

Posner, M. L. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Radlo, S. J., Steinberg, G. M., Singer, R. N., Barba, D. A., & Melnikov, A. (2002). The influence of an attentional focus strategy on alpha brain wave activity, heart rate, and dart-throwing performance. *International Journal of Sport Psychology, 33*, 205-217.

Rothbart, M. K., Ellis, L. K., & Posner, M. I. (2011). Temperament and self-regulation. In K. D. Vohs & R. F. Baumeister (Eds.), *Handbook of Self-Regulation: Research, Theory, and Applications* (*2nd Ed.*) (pp. 441-460). New York: The Guilford Press.

Sage, G. H. (1984). *Motor Learning and Control: A Neuropsychological Approach*. Dubuque: Wm. C. Brown.

Sayette, M. A., & Griffin, K. A. (2011). Self-regulatory failure and addiction. In K. D. Vohs & R. F. Baumeister (Eds.), *Handbook of Self-Regulation: Research, Theory, and Applications* (*2nd Ed.*) (pp. 505-521). New York: The Guilford Press.

Schinke, R. J., & Jerome, W. C. (2002). Understanding and refining the resilience of elite athletes: an intervention strategy. *Athletic Insight*, 4.

Schinke, R. J., Peterson, C., & Couture, R. (2004). A protocol for teaching resilience to high performance athletes. *Journal of Excellence, 9,* 9-18.

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).

Seligman, M. E. P., Nolen-Hoeksema, S., Thornton, N., & Moe-Thornton, K. (1990). Explanatory style as a mechanism of disappointing athletic performance. *Psychological Science, 1*, 143-146.

Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: identifying diagnostic conditions. *Developmental Psychology, 28*, 978-986.

Smith, M. D., & Chamberlin, C. J. (1992). Effect of adding cognitively demanding tasks on soccer skill performance. *Perceptual and Motor Skills, 75*, 955-961.

Stillman, T. F., Tice, D. M., Fincham, F. D., & Lambert, N. M. (2009). The psychological presence of family improves self-control. *Journal of Social and Clinical Psychology, 28*, 498-529.

Suchy, Y. (2009). Executive functioning: Overview, assessment, and research issues for non-neuropsychologists. *Annals of Behavioral Medicine, 37*, 106-116.

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*, 271-324.

Van Raalte, J. L., Brewer, B. W., Lewis, B. P., Linder, D. E., Wildman, G., & Kozimor, J. (1995). Cork! The effects of positive and negative self-talk on dart throwing performance. *Journal of Sport Behaviour, 18*, 50-57.

Vohs, K. D., Baumeister, R. F., & Ciarocco, N. J. (2005). Self-regulation and self-presentation: regulatory resource depletion impairs impression management and effortful self-presentation depletes regulatory resources. *Journal of Personality and Social Psychology, 88,* 632-657.

Wagner, D. D., & Heatherton, T. F. (2010). *Expending cognitive efforts leads to emotional dysregulation.* Manuscript submitted for publication.

Wagner, D. D., & Heatherton, T. F. (2011). Giving in to temptation: The emerging cognitive neuroscience of self-regulatory failure. In K. D. Vohs & R. F. Baumeister (Eds.), *Handbook of Self-Regulation: Research, Theory, and Applications* (*2nd Ed.*) (pp. 41-63). New York: The Guilford Press.

Wallace, H. M. & Baumeister, R. F. (2002). The effects of success versus failure feedback on further self-control. *Self and Identity, 1,* 35-41.

Weidenbeck, S. (1985). Novice/expert differences in programming skills. *International Journal of Man-Machine Studies, 23*, 383-390.

Weinburg, R. S., & Hunt, V. V. (1976). The interrelationships between anxiety, motor performance and electromyography. *Journal of Motor Behavior, 8*, 219-224.

Wills, T. A., & Dishion, T. J. (2004). Temperament and adolescent substance use: A transactional analysis of emerging self-control. *Journal of Clinical Child and Adolescent Psychology, 33*, 69-81.

Wright, R. A., Junious, T. R., Neal, C., Avello, A., Graham, C., Herrmann, L., … Walton, N. (2007). Mental fatigue influence on effort-related cardiovascular response: Difficulty effects and extension across cognitive performance domains. *Motivation and Emotion, 31*, 219-231.

Wright, R. A., Stewart, C. C., & Barnett, B. R. (2008). Mental fatigue influence on effort-related cardiovascular response: Extension across the regulatory (inhibitory)/non-regulatory performance dimension. *International Journal of Psychophysiology, 69*, 127-133.

Zimmerman, B. J., & Kitsantas, A. (1997). Developmental phases in self-regulation: shifting from process to outcome goals. *Journal of Educational Psychology, 89*, 29-36.

Table 1

Descriptive Statistics for Participant Characteristics, Manipulation Checks, and Trait Self-Control and Psychological Resilience Questionnaires

	Control Group (Mean ± SD)	Experimental Group (Mean ± SD)	p-value
Sex			0.210
Males	18 (58%)	13 (42%)	
Females	13 (42%)	18 (58%)	
Age	22.65 ± 3.24	22.97 ± 4.61	0.751
Dart experience			0.081
Never	6 (19%)	11 (35%)	
Once per year	18 (58%)	17 (55%)	
Once every few months	7 (23%)	3 (10%)	
Ratings of Perceived Exertion	1.12 ± 1.25	1.61 ± 1.57	0.178
Visual Analogue Scale	29.82 ± 18.19	38.3 ± 15.83	0.063
Mood			
Pleasant-Unpleasant	21.4 ± 13.17	17.97 ± 11.18	0.273
Arousal-Calm	8.31 ± 6.07	9.26 ± 6.53	0.554
Positive-Tired	-11.24 ± 8.5	-12.42 ± 7.16	0.558
Negative-Relaxed	-37.27 ± 8.98	-35.65 ± 8.40	0.463
Trait self-control	45.48 ± 7.13	44.03 ± 7.49	0.437
Resilience	28.32 ± 5.09	27.65 ± 5.56	0.619

Table 2

Descriptive Statistics for Outcome Measures at Round One and Round Two

	Control Group (Mean ± SD)	Experimental Group (Mean ± SD)	p-value
Round 1 mean accuracy (cm)	11.41 ± 4.29	11.25 ± 2.42	0.862
Round 2 mean accuracy (cm)	10.61 ± 3.13	12.18 ± 2.64	**0.038**
Round 1 accuracy standard deviation (cm)	6.33 ± 2.83	5.71 ± 1.14	0.264
Round 2 accuracy standard deviation (cm)	5.94 ± 1.82	7.08 ± 1.93	**0.019**
Round 1 mean reaction time (s)	1.04 ± 0.27	1.12 ± 0.34	0.532
Round 2 mean reaction time (s)	1.02 ± 0.32	1.11 ± 0.39	0.420
Round 1 reaction time standard deviation (s)	0.33 ± 0.13	0.31 ± 0.13	0.532
Round 2 reaction time standard deviation (s)	0.24 ± 0.12	0.29 ± 0.12	0.148
Round 1 mean peak biceps activation	0.16 ± 0.13	0.19 ± 0.16	0.446
Round 2 mean peak biceps activation	0.16 ± 0.13	0.21 ± 0.18	0.236
Round 1 mean peak triceps activation	0.47 ± 0.24	0.54 ± 0.30	0.314
Round 2 mean peak triceps activation	0.49 ± 0.22	0.58 ± 0.25	0.121

Table 3

Multiple Regression Assessing the Moderating Effects of Trait Self-Control and Experimental Condition for Predicting Round Two Mean Accuracy

	B	*SE B*	ß	p-value
Constant	4.16	0.88		**<0.001**
Round 1 mean accuracy	0.63	0.07	0.74	**<0.001**
Condition	0.83	0.25	0.28	**0.001**
Centered trait self-control	-0.01	0.04	-0.02	0.790
Condition x Centered trait self-control	-0.07	0.04	-0.17	**0.044**

Note. Outcome variable: round two mean accuracy scores; $R^2 = .61$, adjusted $R^2 = .58$, $F(4, 57) = 22.06$, $p < 0.001$.

Table 4

Multiple Regression Assessing the Moderating Effects of Psychological Resilience and Experimental Condition for Predicting Round Two Mean Accuracy

	B	*SE B*	ß	p-value
Constant	3.88	0.96		**<0.001**
Round 1 mean accuracy	0.66	0.08	0.77	**<0.001**
Condition	0.85	0.25	0.29	**0.001**
Centered resilience	0.06	0.05	0.10	0.285
Condition x Centered resilience	-0.05	0.05	0.09	0.333

Note. Outcome variable: round two mean accuracy scores; $R^2 = .59$, adjusted $R^2 = .56$, $F(4, 57) = 20.49$, $p < 0.001$.

Table 5

Multiple Regression Assessing the Moderating Effects of Trait Self-Control and Experimental Condition for Predicting Round Two Mean Reaction Time

	B	*SE B*	ß	p-value
Constant	-0.09	0.07		.231
Round 1 mean reaction time	1.07	0.07	0.92	**<0.001**
Condition	0.00	0.02	-0.01	0.841
Centered trait self-control	0.00	0.03	0.02	0.692
Condition x Centered trait self-control	0.00	0.03	-0.09	0.106

Note. Outcome variable: round two mean reaction time scores. $R^2 = .83$, adjusted $R^2 = .82$, $F(4, 57) = 69.27$, $p < .001$

Table 6

Multiple Regression Assessing the Moderating Effects of Psychological Resilience and Experimental Condition for Predicting Round Two Mean Reaction Time

	B	*SE B*	ß	p-value
Constant	-0.08	0.08		0.298
Round 1 mean reaction time	1.06	0.07	0.91	**<0.001**
Condition	0.00	0.02	-0.01	0.837
Centered resilience	0.00	0.004	0.02	0.798
Condition x Centered resilience	0.00	0.004	-0.04	0.445

Note. Outcome variable: round two mean reaction time scores. R^2 = .82, adjusted R^2 = .81, $F(4, 57) = 66.22$, $p < .001$.

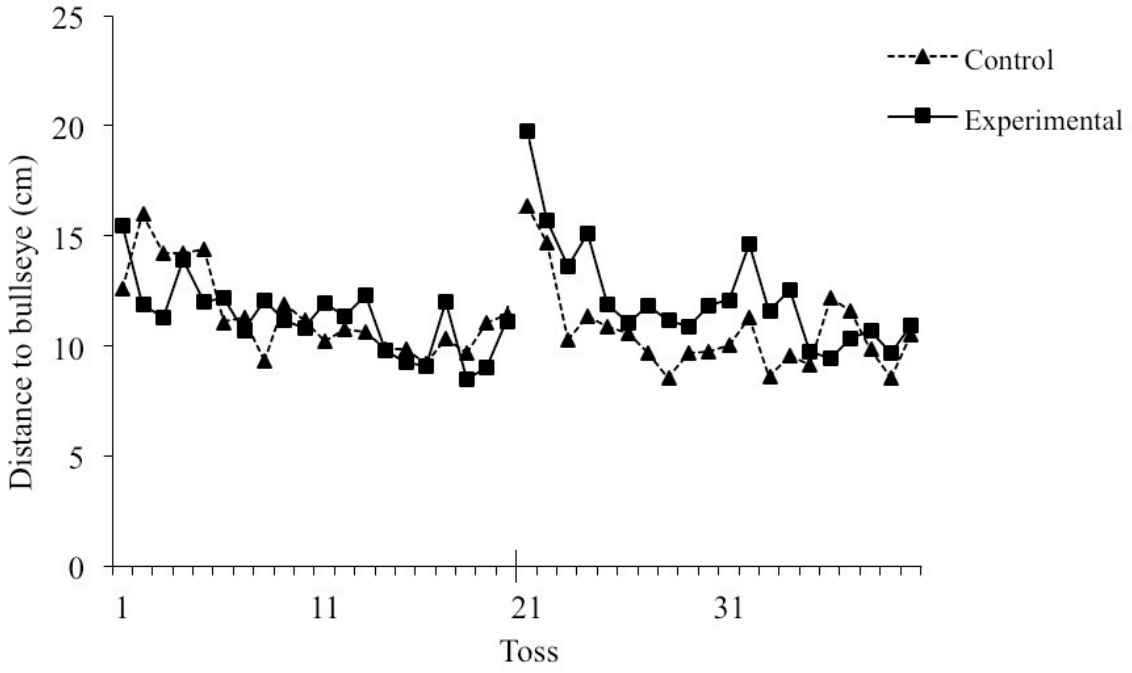

Figure 1. Mean accuracy for each toss. Tosses 1-20 constituted the first round of dart tossing, while tosses 21-40 constituted the second round.

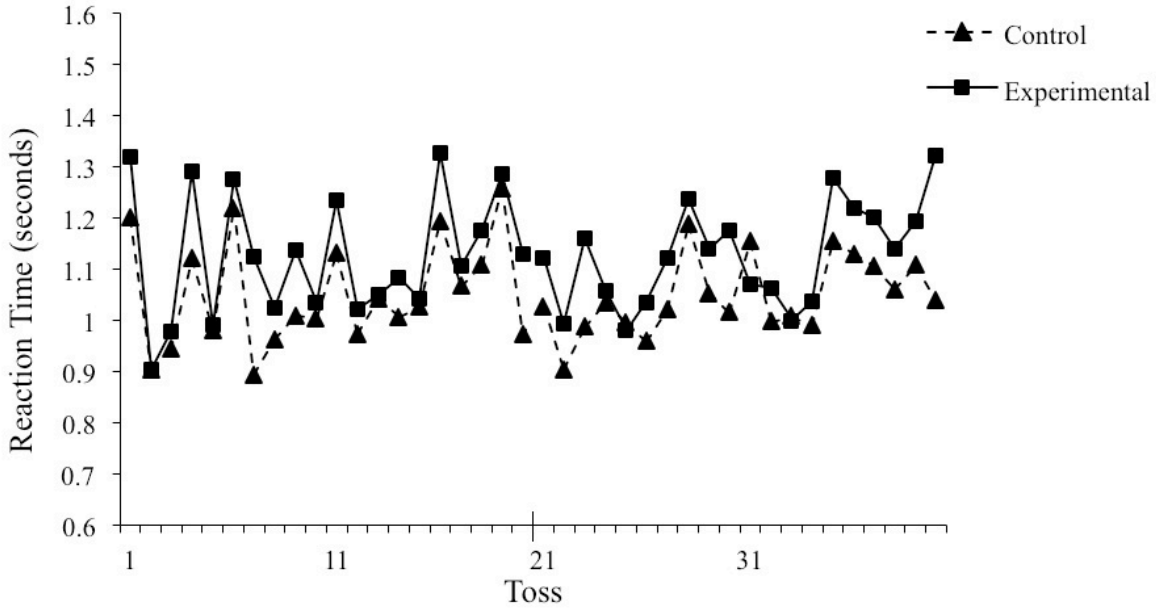

Figure 2. Mean reaction time for each toss. Tosses 1-20 constituted the first round of dart tossing, while tosses 21-40 constituted the second round.

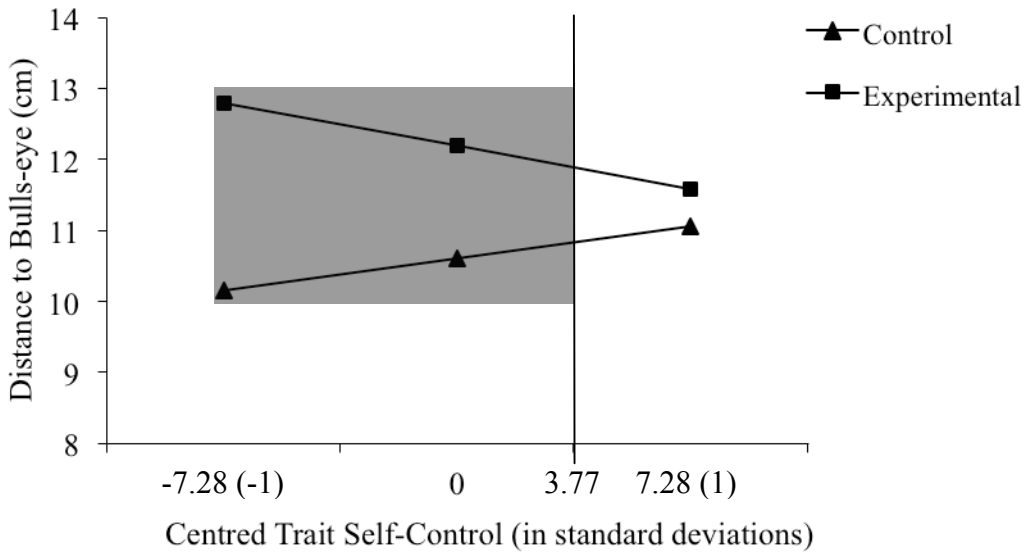

Figure 3. Moderating effects of trait self-control on mean accuracy. The region below the trait self-control score of 3.77 crossed the significance level, $p < .05$. The shaded area represents this region of significance.

Appendix A: Recruitment Poster

McMaster University

Throw some darts… make $20!

PARTICIPANTS NEEDED FOR
RESEARCH IN THE DEPARTMENT OF KINESIOLOGY

You will be asked to complete a **dart-tossing task**, a cognitive task, and answer various questionnaires.

The research session will take approximately 30 minutes to complete.

In appreciation for your time and effort, **you will receive $20**!

For more information about this study, or to volunteer for this study, please contact:
Desmond McEwan
Department of Kinesiology
Email: xxxxxxx@mcmaster.ca

This study has been reviewed by, and received ethics clearance by the McMaster Research Ethics Board.

Appendix B: Email to Students who had Previously Agreed to Participate in Research Projects in the McMaster Health & Exercise Psychology Lab

Hello,

Thank you for your recent participation in a Department of Kinesiology research study on self-regulation and physical activity. At the time, you indicated that you might be interested in participating in future Kinesiology studies. Desmond McEwan and Dr. Kathleen Martin Ginis are currently recruiting for a study that extends the research you previously participated in.

The study involves a 30-minute commitment and you will be given $20 for your participation. I have attached a description of the study [Appendix A poster]. The study involves completing a dart-tossing task, a cognitive task, and a few questionnaires.

If you might be interested, please respond to this email if you have any questions or to confirm that you would like to participate.

Thanks again for your initial interest and we hope to hear from you soon!

Appendix C: Letter of Information/Consent Form

DATE: _____

LETTER OF INFORMATION / CONSENT

A Study of/about The Effects of Depleted Self-Regulation on Athletic Performance

Investigators: Desmond McEwan and Dr. Kathleen Martin Ginis

Principal Investigator: Desmond McEwan
Department of Kinesiology
McMaster University
Hamilton, Ontario, Canada
XXX XXX-XXXX
xxxxxxx@mcmaster.ca

Co-Investigator(s): Faculty Supervisor: Dr. Kathleen Martin Ginis
Department of Kinesiology
McMaster University
Hamilton, Ontario, Canada
XXX XXX-XXXX
xxxxxxx@mcmaster.ca

Purpose of the Study
The purpose of this study is to discover how various mental tasks affect performance on an athletic task. Specifically, we would like to see how you perform on a dart-tossing task and a cognitive task and if these two are related.

Procedures involved in the Research

Should you choose to participate in this study, there will be a series of tasks for you to complete:

1. A dart-tossing task. You will be asked to complete a round of dart tossing towards a dartboard.

2. A cognitive task. This will be a word-matching task. This will take 5 minutes to complete.

3. A questionnaire about how you are feeling at this point in the study. This will take a couple minutes to complete.

4. A second dart-tossing task, similar to the first round.

5. Two final questionnaires regarding some traits about yourself. This will take a couple minutes to complete.

In total, we anticipate that this study will take approximately 40 minutes to complete.

Potential Harms, Risks or Discomforts:

As this study involves some physical exertion, you may feel fatigued during or after the study. Feel free to do some light stretching before and after the study session to help alleviate any muscle soreness.

You can withdraw (stop taking part) at any time during this study. I describe below the steps I am taking to protect your privacy.

Potential Benefits

We hope that you will benefit from participation in this study by going through the research process in a scientific study.

You participation will help benefit the scientific community by providing information on the relationship between mental and physical tasks.

Payment or Reimbursement

You will receive $20 as a thank you for your time and effort in participating in this study.

Confidentiality

You are participating in this study confidentially. I will not use your name or any information that would allow you to be identified. No one but myself and the research assistant will know whether you participated unless you choose to tell them.

The information you provide on the physical and mental tasks, as well as in the questionnaires will be entirely confidential. By assigning you a participant ID number, I will not be able to see what answers you gave when I analyze the data from this study. All information you provide will be kept in a locked cabinet in which only I will have access to and information kept on a computer will be protected by a password.

Participation and Withdrawal

Your participation in this study is entirely voluntary. It is your choice to be part of the study or not. If you decide to be part of the study, you can decide to stop (withdraw), at any time, even after signing the consent form or partway through the study. If you decide to withdraw, there will be no consequences to you. In cases of withdrawal, any data you have provided will be destroyed unless you indicate otherwise. If you do not want to answer some of the items from the questionnaires, you do not have to but you can still be in the study.

Information about the Study Results
I expect to have this study completed by approximately December 2011. If you would like a brief summary of the results, please let me know how you would like it sent to you.

Questions about the Study
If you have questions or need more information about the study itself, please contact me at:
Desmond McEwan
McMaster University – Department of Kinesiology
XXX XXX-XXXX
mcewand@mcmaster.ca

This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance.
If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat
Telephone: XXX XXX-XXXX
c/o Research Office for Administrative Development and Support
E-mail: xxxxxx@mcmaster.ca

CONSENT

I have read the information presented in the information letter about a study being conducted by Desmond McEwan of McMaster University.

I have had the opportunity to ask questions about my involvement in this study and to receive additional details I requested.

I understand that if I agree to participate in this study, I may withdraw from the study at any time. I have been given a copy of this form.

I agree to participate in the study.

Signature: _____

Name of Participant (Printed) _____

Please check one of the boxes below:
☐ *Yes, I would like to receive a summary of the study's results.*
Please send them to this email address _____

☐ *No, I do not want to receive a summary of the study's results.*

Appendix D: Demographic Questionnaire

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

Age: _____

Sex: Female _____ Male _____

Have you played darts before? (please check one)
__ Yes, I currently play competitively (i.e., in a dart-tossing league)
__ Yes, I've played competitively in the past but not now
__ Yes, but only recreationally (i.e., with friends)
__ No, I have never played darts before

If you answered **"yes"** to the above question, please indicate how often you play darts, on average (please check one):
__ At least once per week
__ At least once per month
__ Once every few months
__ Once per year

Appendix E: Example Stroop Task Items

Matched (non-depleting)	Modified (depleting)
RED	RED
BLUE	BLUE
GREEN	GREEN
BLUE	BLUE
BLACK	BLACK
YELLOW	YELLOW
GREEN	GREEN
ORANGE	ORANGE
GREEN	GREEN
RED	RED
PINK	PINK
BLACK	BLACK
BROWN	BROWN
YELLOW	YELLOW
GRAY	GRAY
BLUE	BLUE
GREEN	RED

Appendix F: Rating of Perceived Exertion Questionnaire

RATINGS OF PERCEIVED MENTAL EXERTION (RPE)

Please indicate how much mental exertion you believe you've expended by **circling one of the following numbers**:

0 Nothing at all

0.3

0.5 Extremely weak

1 Very weak

1.5

2 Weak

2.5

3 Moderate

4

5 Strong

6

7 Very Strong

8

9

10 Absolute Maximum

Appendix G: Visual Analogue Scale

VAS FATIGUE SCALE

Make a line through the bar to indicate how energized or tired you feel at this moment

Extremely Tired | **Extremely Energized**

Appendix H: Brief Mood Inspection Scale

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 <u>Not</u> Feel						**Definitely Do Feel**

9. Nervous

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

10. Calm

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

11. Gloomy

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

12. Fed up

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

13. Sad

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

14. Jittery

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

15. Grouchy

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

16. Content

1	2	3	4	5	6	7
Definitely Do <u>Not</u> Feel						**Definitely Do Feel**

Appendix I: Trait Self-Control Questionnaire

TRAIT SELF-CONTROL

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 am good at resisting temptation. _____
2. I have a hard time breaking bad habits. _____
3. I am lazy. _____
4. I say inappropriate things. _____
5. I do certain things that are bad for me if they are fun. _____
6. I refuse things that are bad for me. _____
7. I wish I had more self-discipline. _____
8. People would say that I have iron self-discipline. _____
9. Pleasure and fun sometimes prevent me from getting work done. _____
10. I have trouble concentrating. _____
11. I am able to work effectively toward long-term goals. _____
12. Sometimes I can't stop myself from doing something, even if I know it's wrong. _____
13. I often act without thinking through all the alternatives. _____

Appendix J: Connor-Davidson Resilience Scale

Please answer the following items as they apply to you. There are no right or wrong answers. Please **write a number** (0 – 4) in the blanks provided 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.

0	1	2	3	4
Not at all like me		**Sometimes like me**		**Very Much like me**

1. I am able to adapt to change. ____

2. I can deal with whatever comes my way. ____

3. I try to see the humourous side of problems. ____

4. Coping with stress strengthens me. ____

5. I tend to bounce back after illness or hardship. ____

6. I believe I can achieve my goals despite obstacles. ____

7. Under pressure, I can focus and think clearly. ____

8. I am not easily discouraged by failure. ____

9. I think of myself as a strong person. ____

10. I can handle unpleasant feelings. ____

Appendix K: Scoring Chart

Participant ID #:

Round: 1

Throw (time of cue)	Distance (cm) From Target	Reaction Time
1. (4 sec)		
2. (10 sec)		
3. (1 sec)		
4. (7 sec)		
5. (1 sec)		
6. (7 sec)		
7. (10 sec)		
8. (4 sec)		
9. (10 sec)		
10. (1 sec)		
11. (4 sec)		
12. (7 sec)		
13. (4 sec)		
14. (10 sec)		
15. (1 sec)		
16. (7 sec)		
17. (4 sec)		
18. (1 sec)		
19. (7 sec)		
20. (10 sec)		

GROUP:

Round: 2

Throw	(time of cue)	Distance (cm) From Target	Reaction Time
1.	**(7 sec)**		
2.	**(1 sec)**		
3.	**(4 sec)**		
4.	**(7 sec)**		
5.	**(10 sec)**		
6.	**(4 sec)**		
7.	**(1 sec)**		
8.	**(7 sec)**		
9.	**(4 sec)**		
10.	**(4 sec)**		
11.	**(7 sec)**		
12.	**(10 sec)**		
13.	**(10 sec)**		
14.	**(1 sec)**		
15.	**(1 sec)**		
16.	**(10 sec)**		
17.	**(7 sec)**		
18.	**(10 sec)**		
19.	**(1 sec)**		
20.	**(4 sec)**		

Appendix L: Debriefing Script/Form

Thank you for taking part in this study. I realize that performing the physical tasks may have been challenging for you and I appreciate your effort.

In this study we are comparing the effects of what is termed "self-regulatory depletion" on athletic performance. In essence, self-regulation is refers to any effort by a human being to alter its own inner states or responses, such as task performance. It is believed that we all have a limited central nervous system resource where we draw on self-regulatory strength to achieve our goals. When this resource is depleted, we may be unable to perform as well as we would like on another task.

On the cognitive task in which you were asked to match the word of a color with the font color, you were assigned to one of two conditions. In the control (non-depleting) condition, the printed word of the color and its font color matched. In the experimental (depleting) condition, the printed word of the color and the font color did not match. Thus, based on previous research, it is likely that participants in the depleting condition had to exert more cognitive effort, felt more fatigued, and had poorer moods than participants in the non-depleting condition. We wanted to see if the condition in which participants were in affected their performance on an athletic task. Specifically, we hypothesized that those in the depleting task were unable to perform as well as those in the non-depleting task because they had to use up more of the aforementioned self-regulatory resource.

We do not know how the results of the study will work out until we have analyzed the data. If you are interested in receiving an executive summary of the findings, please provide a contact email address on the sheet where you sign for having received your honorarium for the study (if you did not already do so when you signed the consent form) and we will send it to you when it is available.

If you are interested in self-regulation, please feel free to read the following article, which offers a synopsis of the hypotheses and research on self-regulatory depletion:

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin, 136*, 495-525.