SELF-CONTROL DEPLETION AND EXERCISE PERFORMANCE: MECHANISMS OF THE EFFECT

By

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Abstract

This thesis is presented as a collection of four studies in which the mechanisms underpinning the effects of prior self-control exertion on subsequent physical performance are examined. Considerable evidence has demonstrated that the initial exertion of self-control on one task impairs performance on a subsequent physical task, also requiring self-control. However, more sport specific performance tasks are required to improve the ecological validity of self-control exertion research. For example, no research to date has investigated the impact of self-control exertion on repeated running sprint task performance. Moreover, research into the mechanisms that underpin the effect is limited and inconsistent. Individual's perceptions of pain and motivation have been suggested as possible mechanisms, however, further research is required to establish these, and other, mechanisms explaining why self-control interferes with subsequent performance on a physical task. Building on this work, individuals' perceptions of boredom have also been suggested as a potential mechanism, however, boredom is yet to be empirically investigated. Finally, considering the negative effects of self-control exertion on subsequent physical performance, there is a requirement for intervention strategies. In particular, the potential for a goal priming intervention to attenuate the effects of prior self-control exertion on subsequent physical performance has not been investigated to date. The current thesis aims to address these limitations and extend the literature.

Chapter Two examined the effects of self-control exertion on subsequent physical performance, as well as the mechanisms underpinning the effect under a meta-analytical lens. The meta-analysis highlighted significant gaps in the literature, particularly regarding performance task type and a lack of research into the underpinning mechanisms. Therefore, Chapter Three, Four, and Five employed a sequential-task paradigm to address these gaps in the literature. Specifically, Chapter Three examined the potential effects of prior self-control exertion on subsequent repeated running sprint performance. Chapter Four investigated perceptions of boredom as a novel underpinning mechanism that may explain why self-control exertion affects subsequent physical performance. Finally, Chapter Five examined whether a goal priming intervention could attenuate any decrements in performance on a subsequent physical task due to initial self-control exertion.

Overall, the findings of this thesis support the notion that the prior exertion of self-control results in performance decrements during subsequent physical performance tasks. In addition, initial perceptions of pain, motivation, and self-efficacy are suitable underpinning

mechanisms of the effect. More specifically, Chapter Two (meta-analysis) found that self-control exertion had a medium sized negative effect on subsequent physical performance ($g = -0.55$). In addition, a small increase in initial perceptions of pain ($g = 0.18$) and a medium sized reduction in self-efficacy ($g = -0.48$) following self-control exertion were revealed. However, performance task type and study design must be carefully considered as these moderators can influence results. Chapter Three found that prior self-control exertion does not influence subsequent repeated running sprint task performance (all $p > 0.05$). Furthermore, Chapter Four found a negative effect of self-control exertion on wall-sit task performance ($p = 0.05$). In addition, self-control exertion resulted in higher overall perceptions of pain ($p = 0.02$) and reduced overall ($p = 0.01$) and initial ($p = 0.02$) motivation. Perceptions of boredom did not seem to be an underpinning mechanism ($p = 0.79$); however, initial self-control tasks may increase boredom and should be controlled for. Finally, Chapter Five found that a goal priming intervention did not attenuate the effects of prior self-control exertion on a subsequent physical task ($p = 0.28$).

In summary, the current thesis has offered evidence for the negative impact of prior self-control exertion on subsequent physical performance, as well as the potential for self-efficacy and motivation to be underpinning mechanisms to explain the effect. However, findings may be due to physical task type. Future research should continue to investigate the decision-making processes required following the exertion of self-control, as these may influence the performance results observed during subsequent physical task performance.

List of publications arising from this thesis

Peer reviewed journal articles:

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Dedications

To Grandma,

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Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter One

Literature Review

Defining Self-Control

Self-control is defined as an individual's ability to alter, modify, change, or override, their impulses, desires, and habitual responses to aid the regulation of behavior to attain a desired end state or goal (Baumeister, Vohs & Tice, 2007). Self-control is understood to only be exerted when a temptation has the potential to direct behavior out of line with an individual's broader long-term goals (Graham & Brown, 2020). Within the literature, self-control has been associated with several alternative terms, including *willpower, self-discipline, and self-regulation* (Duckworth & Seligman, 2005; Henden, 2008). Specifically, self-control and self-regulation are most frequently used interchangeably (Baumeister et al., 2007). It is however important to distinguish between self-control and self-regulation; self-regulation is considered an umbrella term that captures automatic and nonconscious regulatory processes, whereas self-control has been categorized as a specific form of self-regulation in which an individual exerts deliberate and conscious effort to control the self (Baumeister et al., 2007).

Trait or dispositional self-control is defined as ones' general capability to alter their responses to achieve a desired state or outcome that would not arise naturally (Bauer & Baumeister, 2011). This capacity is suggested to be relatively consistent across situations and over time. In essence, individuals with high trait self-control are better at controlling habitual responses than those individuals with low trait self-control (de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012). Exhibiting high levels of self-control is beneficial for a large range of adaptive behaviors including improved wellbeing (e.g., de Ridder & Gillebaart, 2017), enhanced academic achievement (e.g., Duckworth & Seligman, 2005), and better interpersonal relationships (e.g., Righetti & Finkenauer, 2011). As a result, high self-control has been associated with nearly all forms of behavior that contribute to a successful and healthy life; therefore, it has become an important psychological phenomenon (de Ridder, van der Weiden, Gillebaart, Benjamins & Fekke Ybema, 2020). More specifically, self-control is important in an array of sport and exercise settings, including athletic performance (Englert, 2016, 2017). For instance, athletes must regulate emotions in high-pressure environments (e.g., sporting competitions; Englert & Bertrams, 2012) as well as adhere to strict training regimes over a prolonged period of time (Gillebaart & Adriaanse, 2017).

It is also recognized that the ability to exert self-control can differ across situations within the same individual (i.e., state self-control; Gailliot et al., 2012). This state perspective of self-control proposes that the initial exertion of self-control on one task impairs performance on a subsequent, seemingly unrelated task, also requiring self-control (Dang, 2017; Hagger et al., 2010). For example, athletes are required to control their cognitive, emotional, and motor processes, as well as behavioral impulses to optimize sporting performance (Englert & Bertrams, 2012). In addition, athletes must force themselves to work persistently during strenuous physical exercise despite the desire to relieve effort to reduce the discomfort associated with achieving optimal performance (Wagstaff, 2014). All the examples mentioned above are crucial to succeed in sport and exercise. Therefore, self-control seems to be an important factor for athletic achievement as well as exercise participation and adherence (Boat & Cooper, 2019).

Self-Control Exertion and Subsequent Task Performance

To assess the state perspective of self-control, researchers frequently employ the *sequential-task paradigm* (Baumeister et al., 2007). Within this protocol, participants are randomly assigned to either an experimental (self-control) or control (non-self-control) condition. In the self-control condition, both tasks require self-control. However, in the non-self-control condition, only the second task requires self-control, while the primary task does not require any, or very little, self-control exertion (Baumeister, Bratslavsky, Muraven, & Tice, 1998). Research suggests that the self-control condition group performance on the second self-control task is impaired, when compared to the non-self-control condition group, due to the initial exertion of self-control on the first task (Baumeister et al., 1998). This effect is commonly referred to as the 'ego-depletion effect' (Friese et al., 2019) For example, following a self-control task (transcribing task with instructions to omit the letters "e" and "n"), participants consumed a higher number of unhealthy snacks during an ad-libitum taste test, when compared to those who completed a non-self-control task (transcribing task with no letter omission instructions) (Friese, Engeler & Florack, 2015). Resisting the urge to transcript the letter "e" and "n" requires attentional control and motor inhibition (Baumeister et al., 1998); resulting in reduced performance on a subsequent task that requires self-control. The "ego depletion effect" has been replicated on several occasions (e.g., Baumeister et al., 1998; Baumeister & Vohs, 2007; Wright, Martin, & Bland, 2003).

A number of meta-analyses have provided support for the ego-depletion effect across a range of performance domains. The most cited is a collection of studies between 1998 and 2009 that have employed the sequential task paradigm (Hagger et al., 2010). The meta-analysis revealed a medium effect size (d = 0.62) for impaired performance on the second self-control task due to the prior exertion of self-control. In the studies included in this meta-analysis, a range of performance outcomes were used, such handgrip task performance, solvable anagram task performance, food taste tests, math or mental arithmetic task performance, and modified Stroop task performance. While such meta-analytical evidence provides support for the ego-depletion effect (Dang, 2017; Hagger et al., 2010), the true size of the effect has been doubted, with researchers suggesting that the effect sizes may have been exaggerated due to publication bias. For instance, re-analysis of Hagger et al.'s (2010) data (Carter & McCullough, 2014, g = 0.48) and a subsequent meta-analysis which included unpublished research (Carter, Kofler, Forster, & McCullough, 2015, g = 0.24), revealed 'small study' bias in the effect size originally reported. In conclusion, it was reported that the evidence base suggesting initial usage of self-control leads to performance decrements on subsequent self-control tasks was uncertain.

However, researchers have subsequently questioned the interpretation of the regression analyses conducted in Carter et al.'s (2015) meta-analysis (e.g., Cunningham & Baumeister, 2016; Hagger & Chatzisarantis, 2014). As a result, a registered multi-lab replication of the depletion effect was conducted (Hagger et al., 2016). Multiple studies (k = 23, total N = 2141) performed replications of a standardized protocol based on the sequential-task paradigm originally used by Sripada, Kessler, and Jonides (2014). Findings failed to demonstrate support for the ego-depletion effect and suggested the size of the effect is close to zero. Such evidence raises questions to the existence of the ego-depletion effect altogether. Building on the literature, a more recent, up-to date meta-analysis, employing a stricter inclusion criterion (e.g., including studies that tested the effectiveness of each depleting task), revealed a small-to-medium effect for the prior exertion of self-control on subsequent task performance (g = 0.39) (Dang, 2017). Dang's (2017) meta-analysis proposed that selecting an effective depletion task was imperative to observing the ego depletion effect. Considering all the evidence, it is clear the ego depletion effect warrants further investigation. Developing a unification regarding methodologies and best practices must be agreed to understand the true size of the effect (Dang, 2017, Hagger et al., 2016).

Self-Control Exertion and Subsequent Physical Task Performance

Despite the ongoing debates, within a sport and exercise domain, an extensive body of research concurs that the prior self-control exertion negatively impacts performance on a subsequent physical task that also requires self-control (Englert, 2016, 2017). To demonstrate the negative effects of prior self-control exertion, several early studies utilised an isometric handgrip task as a simple measure of physical performance. This task is suitable as squeezing an isometric handgrip task requires muscular strength, whereby an individual is required to overcome fatigue and the urge to quit, alongside also requiring self-control and mental persistence (Bray, Martin Ginis, Hicks, & Woodgate, 2008). For example, participants who completed an incongruent Stroop task (self-control condition) squeezed an isometric handgrip dynameter for significantly less time than participants who completed a congruent Stroop task (non-self-control condition) (Graham, Li, Bray & Cairney, 2018). The potential for prior self-control exertion to reduce subsequent isometric handgrip task performance has been replicated in numerous other studies (e.g., Bray et al., 2008; Bray, Graham, Martin Ginis, & Hicks, 2011; Muraven, Tice, & Baumeister 1998; Tice, Baumeister, Shmueli, & Muraven, 2007).

While such studies provide valuable insight into the effects of prior self-control exertion on simple measures of physical strength, there has been a movement to enhance the ecological validity of the evidence so that conclusions regarding more complex human performance can be drawn. Consequently, research has begun to employ more sport-specific measures of physical performance. To date, this has included demonstrating the detrimental effects of self-control exertion on subsequent physical performance in calisthenic persistence tasks (e.g., wall-sit task; Boat & Taylor, 2017; sit-up task; Dorris et al., 2012), skill-based tasks (e.g. Darts; McEwan et al., 2013; Basketball; Englert, Bertrams, et al., 2015), gross motor skill endurance tasks (e.g., cycling; Englert & Wolff, 2015; Boat, Taylor & Hulston, 2017; Wagstaff, 2014) and more recently in complex sporting activities (e.g., Hockey; Boat, Sunderland & Cooper, 2021; Shooting; Englert Dziuba, Giboin, Wolff, 2021; Englert, Dziuba, Wolff, & Giboin, 2021). For instance, following a cognitively demanding task (incongruent Stroop task), hockey players made more errors on a field hockey task compared to when they completed a cognitively simple task (congruent Stroop task) (Boat, Sunderland & Cooper, 2021). The aforementioned studies demonstrate that engaging in a cognitively demanding task that requires self-control reduces performance on a subsequent physical task. This effect has been corroborated by recent meta-analytical evidence that has investigated the effects of cognitive exertion on subsequent physical task performance (Brown et al., 2020; Giboin & Wolff, 2019). To elaborate, a small-to medium negative effect was found for both overall cognitive exertion (g = -0.38) and studies that employed an initial cognitive task lasting < 30 min (a timeframe associated with self-control research) (g = -0.45) on subsequent physical task performance. However, a current gap in the literature is whether prior self-control exertion has a negative impact across other performance domains, such as sprinting or swimming performance.

In particular, it is important to understand the effects of self-control exertion on sprinting performance, given that many athletes (e.g., team sport players) are frequently required to continually reproduce maximal and near maximal sprints with shorts period of recovery over an extended period (Dawson et al. 1997; Bishop et al. 2001). In addition, success in intermittent sports is commonly linked to the ability to perform repeated bouts of high-intensity sprint exercise (Saunders, Sale, Harris & Sunderland, 2014). Therefore, to achieve optimal repeated sprint performance, athletes will require self-control to invest sustained effort to resist discomfort and the temptation to reduce effort (Boat et al., 2021; Taylor et al., 2018). To address this gap, further empirical investigation into the effects of prior self-control exertion on repeated running sprint performance is required. Such investigation is necessary to increase our understanding into the specific performance tasks that are negatively impacted by the prior exertion of self-control.

Although the research discussed above clearly highlights the negative impact of prior cognitive exertion on subsequent physical performance, it must be noted that previous meta-analytical work combined studies that have investigated the effects of self-control and mental fatigue, despite the propositions that there are distinct differences between these two constructs (Englert, 2016, 2019). Research corroborates that mental fatigue can also impair subsequent physical performance. For example, following a 90 min demanding cognitive task (The AX-continuous performance task; Carter, Braver, Barch, Botvinick, Noll, & Cohen, 1998), endurance trained participants quit a subsequent cycling time-to-exhaustion task at 80% peak power output earlier compared to those in the control condition (90 min of watching emotionally neutral documentaries; Marcora, Staiano & Manning, 2009). Therefore, researchers have suggested that ego-depletion may be a brief manifestation of mental fatigue (Inzlicht & Berkman, 2015). In addition, it has been demonstrated that both self-control exertion and mental fatigue may be overcome with adequate task motivation (Muraven & Slessareva, 2003). However, it has been suggested that the duration of initial tasks employed in self-control exertion research (e.g., 4 min Stroop task; Boat et al., 2018) are not long enough to induce subjective feelings of mental fatigue and increased effort (Pageaux, Marcora, & Lepers, 2013). As a result, there may be a significant difference in the self-regulatory and mechanistic processes initiated as self-control is exerted or mental fatigue is induced (Lee, Chatzisarantis & Hagger, 2016). To our knowledge, the mechanisms that underpin self-control have not been investigated under a meta-analytical lens. This would prove useful to provide a consensus regarding which proposed mechanisms of self-control failure appear to be associated with subsequent reductions in physical performance after completing a self-control exertion task (typically 30 minutes or less).

Theoretical Models of Self-Control

Several theoretical models have been established to explain why self-control failures are seen in various performance settings, including sport and exercise contexts. The most traditional theory is *the strength model of self-control*, which implies that individuals possess a limited central resource of self-control, which can become depleted following a period of self-control exertion (Baumeister et al., 1998). Consequently, following the initial exertion of self-control, one's capacity to exert further self-control becomes exhausted, resulting in impaired performance on subsequent acts of self-control (Hagger et al., 2010). While the limited resource perspective has received empirical and meta-analytical support (e.g., Dang, 2017; Hagger et al 2010), it has received strong challenge. For instance, researchers have struggled to attribute a single universal resource that can become depleted (Inzlicht & Friese, 2019). Glucose was previously suggested (Gailliot & Baumeister, 2007); however, these proposals have since been dismissed (Boat et al., 2017; Kurzban, 2010). In addition, when participants were adequately motivated, using techniques such as providing monetary incentives (Brown & Bray, 2017a; Muraven & Slessareva, 2003) and offering choice (Moller et al., 2006), performance decrements on subsequent tasks were not observed. If self-control is a limited and exhaustible resource, then it is unclear why offering choice, for example, can replenish this resource.

To provide a more mechanistic explanation of self-control, alternative models have been established. *The shifting priorities model* (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017) suggests that the initial exertion of self-control results in shifts in attentional and motivational processes. Specifically, a subjective 'valuation' process leads to reductions in self-control, whereby individuals shift foci from distal goals to proximal temptations (Berkman, Livingston, Kahn, & Inzlicht, 2015). Proximal temptations are usually more immediately satisfying and enjoyable, compared to distal goals (Milyavskaya & Inzlicht, 2016). However, distal goals that are autonomous (i.e., freely chosen and of personal meaning; Deci & Ryan, 2012) are less likely to be influenced by proximal temptations (Milyavskaya, Inzlicht, Hope & Koestner, 2015), are perceived as being easier to pursue (Werner, Milyavskaya, Foxen-Craft, & Koestner, 2016), and are less fatiguing (Moller et al., 2006), compared to non-concordant goals. In the context of athletic performance, where goals are often autonomous, factors that cause shifts in motivational and attentional foci are likely to include physiological sensations of discomfort as well as the importance of competition and the competition environment.

A further alternative model is *the opportunity-cost model of self-control* (Kurzban, Duckworth, Kable & Myers, 2014) which suggests self-control failures are due to a cost-benefit analysis that individuals conduct. During this cost benefit analysis individuals conclude that the cost of continually exerting effort in a physical task (e.g., feelings of discomfort or pain during a wall-sit task) do not outweigh the benefits (e.g., optimal performance on a handgrip task). Once it is deemed that the self-control task is no longer valuable enough to offset such an opportunity cost, cognitive processes (e.g., attention) will be offset to an alternative proximal temptation (e.g., quitting the handgrip task). Support for this model derives from research that revealed while self-reported effort (i.e., engagement in the task) remained the same between groups, perceptions of cost (i.e., difficulty, tiredness and frustration) increased in the self-control condition (Wolff, Sieber, Bieleke, Englert, 2019). These increases in cost demonstrate that perceived exertion reflects not the depletion of self-control resources, but instead the increasing intrinsic and/or opportunity costs of exerting prolonged self-control (Wolff & Martarelli, 2020). Taken together, the more recent alternative models of self-control (e.g., *the shifting priorities model*; Inzlicht & Schmeichel, 2016; *opportunity-cost model*; Kurzban et al., 2014) support the idea that self-control failures may be a result of changes in mechanistic processes, whereby the act of continually exerting self-control causes reductions in an individual's desire or "want" to attain a distal goal (Inzlicht & Schmeichel, 2012).

Underpinning Mechanisms of Self-Control Depletion

Perceptions of Pain and Motivation

Establishing the mechanisms underpinning the effects of self-control exertion on subsequent physical performance is vital to develop a more complete understanding of *how* and *why* self-control affects physical performance. Empirical evidence of the *shifting priorities model* in a sport and exercise context is limited; however, research has demonstrated evidence that shifts in perceptions of pain and motivation provide quantifiable shifts in motivational and attentional processes following the initial exertion of self-control. For example, following self-control exertion (4 min incongruent Stroop task) participants held a wall-sit for less time than when they were required to exert no self-control (4 min congruent Stroop task). The performance decrements observed in this study were explained by reduced motivation and increased perceptions of pain (measured via Visual Analog Scales) during the wall-it task, following the exertion of self-control (Boat et al., 2018). Findings suggest that initial self-control exertion may motivate individuals to seek alternative behaviors and cause an individuals' attention to focus on the pain that they are experiencing during the physical task (Boat et al., 2018). As a result, an individual's attention shifts away from the goal of optimal performance, and instead towards the temptation of reducing effort to relieve discomfort. The potential for perceptions of pain and motivation to explain the effects of prior self-control on subsequent physical performance has been replicated in several other studies (e.g., Boat et al., 2020; Boat et al., 2021; Boat & Taylor, 2017). However, some researchers have failed to observe any shifts in motivational and attentional processes (e.g., Brown & Bray, 2017b, 2019; Graham & Bray, 2015; Stocker et al., 2020). Therefore, further exploration of the potential for perceptions of pain and motivation to explain the effects of self-control exertion on subsequent physical performance are required. Moreover, it has been proposed that measuring additional aspects of motivation and attention may provide a better insight into attentional and motivational shifts following the prior exertion of self-control. For example, sustained attention has also been proposed as an underpinning mechanism of self-control. While studies have shown the capacity for self-control to reduce visual attention (gaze behavior) (e.g., Englert, Zwemmer, Bertrams & Oudejans), there is limited research regarding the impact of self-control on cognitive tests of sustained attention in a sport-specific context. Currently, only one previous study has demonstrated the negative impact of self-control on sustained attention. Within this study, following the exertion of self-control (incongruent Stroop task), participants made more errors on the Rapid Visual Information Processing Test (RVIPT) (completed following a hockey skills task) than when they exerted no self-control (congruent Stroop task) (Boat et al., 2021). The RVIPT is a well-established cognitive function test that has been frequently demonstrated as an appropriate measure of sustained attention (e.g., Sun, Cooper, & Tse, 2020). Considering attention is one of the key mechanisms underpinning self-control failure according to *the shifting priorities model* (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), further research is required to examine the effects of self-control exertion on subsequent attention.

In addition, it has been recommended that measuring task importance (i.e., how important is it to achieve optimal performance during this task) may be a further suitable method to measure motivation for goal commitment within a sport and exercise setting (Brown & Bray, 2019). Goal commitment refers to an individual's determination to achieve a goal and has been shown to moderate the relationship between goal-setting and goal-direct behaviors (Klein, Wesson, Hollenbeck, & Alge, 1999), and may be more appropriate to gain domain specific measurements relating to exercise intentions and commitment (Brown & Bray, 2019). Consequently, future research should consider taking measurements of task importance to explicitly measure participant's perceptions of proximal goal focus (i.e., reducing exercise intensity to relieve pain) relative to distal goal focus (i.e., maintaining exercise intensity to achieve optimal performance enhance performance time) (Boat et al., 2021; Inzlicht & Schmeichel, 2016).

RPE

Furthermore, individual's ratings of perceived exertion (RPE) have been suggested as an underpinning mechanism (Wagstaff, 2014). As self-control is exerted, it is suggested that individuals begin to value the level of subjective effort they are employing to be higher, and subsequently reduce effort during a physical task, to lower feelings of physical discomfort. However, support for RPE as an underpinning mechanism is limited and conflicting. For instance, when participants were assigned to the self-control condition (controlling emotions while watching an upsetting video), they reported higher levels of RPE and completed a cycling task slower than participants in the non-self-control condition (no instructions to control emotions while watching an upsetting video) (Wagstaff, 2014). On the contrary, RPE did not differ between self-control exertion (incongruent Stroop task) and non-self-control exertion (congruent Stroop task) conditions in a similar study also employing a cycling physical task (Englert & Wolff, 2015). Inconsistent findings may be a result of how difficult it is to interpret the effects of self-control exertion on subsequent RPE. It has been suggested that while self-control exertion results in individual's reducing the total intensity that they are exercising at, RPE may remain comparable in both the self-control and non-self-control conditions as they perform a physical task. As a result, there is differences in performance but no differences in RPE (Pageaux, 2014; Van Cutsem et al., 2017). Further research is warranted to explore the potential for RPE to explain why the prior exertion of self-control influences subsequent physical performance.

Perceptions of Boredom

Finally, boredom has recently been suggested as an underpinning mechanism that may explain why the prior exertion of self-control influences subsequent physical performance. Research has proposed that boredom may be an attentional mechanism that shifts individuals' attention to engage in alternative tasks (Wolff, Bieleke, Stähler, & Schüler, 2020; Wolff & Martarelli, 2020). According to the *Meaning and Attention Components* (MAC) model, boredom develops when individuals feel they are unable to effectively engage attention in a task and/or when the current activity is perceived as low in meaning or too difficult to complete (Westgate & Wilson, 2018). Once at this conclusion, individuals will become bored. Following increased feelings of boredom, individuals will begin to weigh up the costs (e.g., physical discomfort) and benefits (e.g., optimal performance) of the physical task and begin to seek behavioral alternatives (e.g., quitting the physical task) (Bieleke, Barton, & Wolff, 2021; Kurzban, Duckworth, Kable, & Mywolfers, 2013; Wolff & Martarelli, 2020). Moreover, it may be important to control for boredom as it has been proposed as key to observing the depletion effect in previous research (Mangin, Andréa, Benraissa, Pageaux, & Audiffrena, 2021). It has been suggested that the initial cognitive tasks employed within the sequential task paradigm (e.g., the Stroop task) may increase feelings of boredom, through understimulation (non-self-control tasks) or overstimulation (self-control tasks (Bieleke, Barton, & Wolff, 2021; Wolff & Martarelli, 2020). As a result, the interpretation of findings may be susceptible to the level of boredom that the initial self-control task generates (Wolff & Martarelli, 2020). The impact of prior self-control exertion on perceptions of boredom is yet to be empirically tested within a sport and exercise context, thus providing an important avenue for future research.

Summary

In summary, understanding the mechanisms underpinning the effects of prior self-control exertion or subsequent physical performance is vital to develop a more complete understanding of *how* and *why* self-control exertion negatively affects performance, and to allow for the development of specific targeted interventions aimed at overcoming the effects. At present, increased perceptions of pain and reduced motivation seem to be the most plausible mechanisms to explain why physical performance decreases following the exertion of self-control (Boat et al., 2020). However, further research into the underpinning mechanisms of the effects of prior self-control exertion on subsequent physical task performance is warranted to enhance our understanding of how self-control impacts sport and exercise performance.

Interventions

Interventions to improve self-control and overcome or attenuate the effects of prior self-control exertion are necessary to improve physical performance (Englert, 2019). However, self-control interventions for physical task performance are limited. Previous research has demonstrated that employing a two-week training programme, consisting of repeatedly completing maximal endurance contractions of an isometric handgrip twice daily, can attenuate the negative impact of prior self-control exertion on endurance exercise performance (i.e., maximal graded cycling test) (Bray, Graham & Saville, 2015). Other methods have included offering choice and completing a short mindfulness session once self-control has been depleted (Moller et al., 2006; Stocker, Englert & Seiler, 2019). However, there is currently a lack of interventions that can been employed during the subsequent physical task; an important avenue for future research.

One proposed intervention that can be delivered during physical activity is goal priming, Goal priming involves providing external cues to individuals, which consequently causes changes in cognition and behavior, often without conscious intention or awareness (Papies, 2016). Goal priming has previously been shown to attenuate the effects of prior self-control exertion on subsequent task performance in a non-exercise setting. For example, following the depletion of self-control (via completing difficult anagrams), depleted participants that were primed with self-control goals related to saving money and healthy eating, and had comparable performance to the control group (non-self-control and no goal prime condition) on subsequent measures of self-control strength (impulse buying task and food consumption task) (Walsh, 2014). Findings are promising as they suggest that goal priming could build behviour habits that result in shifts away from proximal temptations, and towards the distal goals that participants are primed with (Walsh, 2014). However, the potential for goal priming to attenuate the effects of self-control depletion during a physical task is yet to be investigated. Goal priming has been used during a physical task to produce higher levels of effort and performance during endurance-based tasks (e.g., Blanchfield, Hardy, Marcora, 2014; Takarada & Nozaki, 2018). Therefore, given the tenants of *the shifting priorities model* (Inzlicht et al., 2014) and previous goal priming research (Blanchfield et al., 2014; Takarada & Nozaki; Walsh, 2014), further research is required to explore if following the exertion of self-control, a self-control goal priming intervention could offset the shifts in attentional and motivational foci away from proximal temptations (e.g., feelings of discomfort and quitting the task) and encourage attainment of the distal goal (e.g., optimal performance) during a subsequent physical performance task.

Summary and Overview of the Thesis

An extensive body of evidence supports the beneficial effects of trait self-control on a large range of adaptive behaviors (e.g., de Ridder et al., 2020). These benefits extend to athletic performance (Englert, 2016, 2017). As well as investigating the trait perspective of self-control, research has employed self-control manipulations and physical performance tasks to examine state self-control. Substantial evidence suggests that performance on subsequent physical tasks is reduced following an initial task requiring self-control (e.g., Boat et al., 2021; Boat & Taylor, 2017; Dorris et al., 2012; Englert, Bertrams, et al., 2015; Englert et al., 2021; McEwan et al., 2013; Wagstaff, 2014). However, the type of physical performance tasks that are negatively impacted by the prior exertion of self-control, and the underpinning mechanisms of the effect, remain unclear. Further meta-analytical research is necessary to highlight potential gaps for novel research in the literature and to pinpoint prominent underpinning mechanisms. For instance, it is currently unknown if prior self-control exertion negatively impacts repeated running sprint performance. Furthermore, boredom has recently been suggested as an underpinning mechanism of self-control exertion (e.g., Wolff & Martarelli, 2020), but this is yet to be empirically tested. Therefore, it is prudent to further examine these lines of enquiry. Finally, interventions to attenuate the detrimental effects of self-control exertion are limited. Goal priming has been demonstrated to attenuate the effects of self-control exertion in non-exercise settings (e.g., Walsh, 2014); thus, as a result, it seems reasonable to investigate the effects of goal priming on attenuating the effects of self-control exertion in a sport and exercise setting. The current thesis aims to achieve these goals.

While the present body of work will aim to achieve these goals, the limitations of the existing literature on the effects of self-control exertion on subsequent physical task performance must be acknowledged. Notably, studies conducted in the field have predominantly been conducted utilizing between-participant designs. In addition, previous meta-analytical evidence has displayed larger effect sizes for studies that have employed a between-subjects design (Brown et al., 2020). While findings have yielded meaningful findings, validity of these findings are threatened due to the effects of individual differences. To combat these individual differences, more recent research has shifted towards employing within-participant designs (e.g., Boat et al., 2021). As such, the current thesis will use a within-subject participant design throughout all experimental chapters (Chapter Three, Chapter Four and Chapter Five), this will allow for the exploration of whether within-participant studies yield comparable effect sizes to between-participant studies. Furthermore, the current thesis recognizes that when investigating the mechanisms that underpin the effects of self-control exertion on subsequent physical performance, the application of previous findings is limited due to the lack of sport-specific measures of physical performance. Consequently, the ecological validity of previous studies, that have investigated the effects of prior self-control exertion on subsequent physical performance, could be questioned. To address this limitation, the current thesis will aim to employ more complex sporting physical tasks (e.g., cycling and repeated running sprints) to enhance the ecological validity of findings. It is hoped that by using sport-specific measures of physical performance, our understanding of how prior self-control exertion impacts subsequent performance in real-world settings will be considerably improved.

Finally, the application of findings to a wider sport-setting are currently somewhat limited due to the lack of sport-specific methods to deplete self-control. While the Stroop task is broadly accepted as a suitable method to induce self-control depletion (e.g., Boat et al., 2020; Brown & Bray, 2019; Graham et al., 2018), it must be acknowledged that the Stroop task is artificial in nature and not sport specific (Englert, 2016). The current thesis recognizes the need for the development of a sport specific measure to deplete self-control, in order to ensure that the conclusions drawn are applicable to sport psychology practitioners. However, these sport specific measures are currently limited (e.g., Englert & Betrams, 2014; Gröpel, Baumeister, & Beckmann, 2014) and are yet to be validated. As a result, to address the aforementioned gaps and limitations in the literature, it is essential to use the well-established Stroop task in a controlled setting (e.g., Boat & Taylor, 2017).

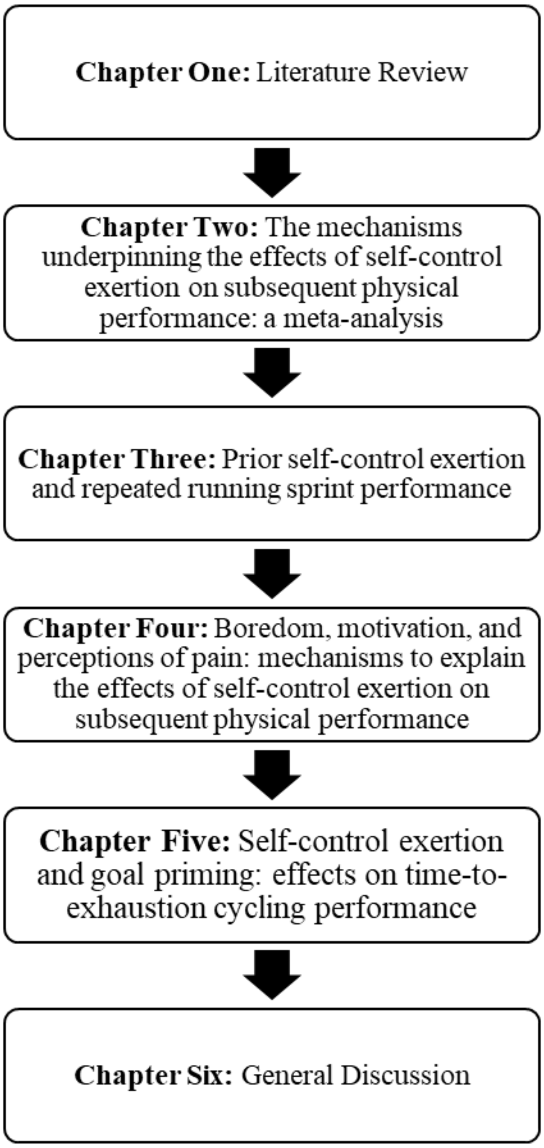
To address these gaps and limitations of the research, this thesis consists of four experimental chapters, followed by a general discussion of key themes and concepts from across the thesis, as follows:

1. **Chapter Two:** A meta-analysis will be conducted to investigate the effects of prior self-control exertion on subsequent physical performance. Furthermore, this chapter will provide the first meta-analytical investigation into the explanatory mechanisms underpinning the effects of prior self-control exertion on subsequent physical performance.

2. **Chapter Three:** Findings from the meta-analysis highlighted multiple gaps and limitations in the literature. This included the need to investigate the effects of prior self-control exertion on more complex sporting physical tasks, as well as the lack of research that has explored the underpinning mechanisms that explain why prior self-control causes performance decrements in subsequent physical task performance. Therefore, chapter three will examine whether exerting self-control affects repeated running sprint performance. In addition, Chapter Three will examine whether any observed effects of self-control exertion could be explained by changes in perceptions of pain, motivation, or RPE.
3. **Chapter Four:** Building on from Chapter Three, Chapter Four will examine if the prior exertion of self-control reduces wall-sit task performance. In addition, Chapter Four will examine perceptions of boredom as a novel mechanism and whether any observed performance decrements can be explained by changes in perceptions of boredom, pain, motivation, and sustained attention.
4. **Chapter Five:** Following the investigation of underpinning mechanisms, the final chapter will aim to evaluate the efficacy of a practical intervention that could attenuate the negative effects of prior self-control exertion during subsequent physical task performance. Chapter Five will examine the potential for a goal prime intervention to attenuate the negative effects of self-control exertion on a time to exhaustion (TTE) cycling task.
5. **General Discussion (Chapter Six):** Following these four investigative chapters, Chapter Six will provide a summary and discussion of the thesis, its key findings, and the practical implication of these findings. In addition, the limitations of the current thesis and future directions for prospective research will be discussed. For a flow diagram displaying an overview of the chapters included in this thesis see Figure 1.1.

Figure 1.1

Flow chart diagram of thesis



Chapter Two

The mechanisms underpinning the effects of self-control exertion on subsequent physical performance: a meta-analysis

Abstract

Prior self-control exertion is consistently reported to cause decrements in subsequent physical performance. However, research into the explanatory mechanisms underpinning the effect is limited and, to our knowledge, has not been assessed under a meta-analytical lens. Therefore, the present study reports a meta-analysis examining the effects of self-control exertion on subsequent physical performance, as well as the mechanisms underpinning the effect. A systematic search of relevant databases was conducted to identify studies that utilized the sequential task paradigm, involving self-control manipulations lasting 30 minutes or less, and examined an aspect of physical performance. Random effects meta-analysis demonstrated that the prior exertion of self-control resulted in a statistically significant medium sized negative effect of prior self-control exertion on subsequent physical performance (g = -0.55). Further analysis revealed a small increase in initial perceptions of pain (g = 0.18) and a medium sized reduction in self-efficacy (g = -0.48); while motivation and RPE were unaffected. The present study provides a novel insight into the mechanisms underpinning the effects of prior self-control exertion on subsequent physical performance. Initial perceptions of pain and self-efficacy appear important mechanisms and thus could be targeted in future interventions aimed at attenuating the effects of self-control exertion to enhance subsequent physical performance.

Key Words: self-control; cognitive exertion; mechanisms; pain; self-efficacy; motivation

Introduction

Self-control is defined as the ability to override and manage dominant response tendencies to regulate one's emotions and behaviors (Vohs & Baumeister, 2004). Exhibiting high levels of self-control is beneficial for a large range of adaptive behaviors; including those related to achievement, task performance, interpersonal functioning, and health (de Ridder, Lensvelt-Mulders, Finkenauer, Roy & Baumeister, 2012). Self-control has also been shown to be important in a magnitude of sport-settings, including athletic performance (Englert, 2016, Englert, 2017), whereby athletes are required to control their impulses and behavioral tendencies to optimize sporting performance. For example, athletes need to force themselves to work persistently during strenuous physical exercise despite the desire to reduce effort to relieve the discomfort associated with achieving optimal performance (Wagstaff, 2014). A further example of the importance of self-control in an exercise setting is where individuals must routinely exert their self-control to persevere at gym work-out routines to achieve personal physical fitness goals (Bandura, 2005; Gillebaart & Adriaanse, 2017). It is however important to distinguish between self-control and self-regulation; self-regulation is considered an umbrella term that captures automatic and nonconscious regulatory processes, whereas self-control has been categorized as a specific form of self-regulation in which an individual exerts deliberate and conscious effort to control the self (Baumeister, Vohs & Tice, 2007).

The ability to exert self-control has been shown to differ between individuals (i.e., trait self-control; Tangney, Baumeister & Boone, 2004), as well as across situations within the same individual (i.e., state self-control; Gailliot, Gitter, Baker & Baumeister, 2012). High levels of trait self-control have been associated with various favourable behaviors important for optimal athletic performance, including training adherence (Englert, 2017). Regarding the state perspective of self-control, contemporary meta-analytical research has supported the notion that the initial exertion of self-control on one task impairs performance on a subsequent, seemingly unrelated task, also requiring self-control (Dang, 2017; Hagger et al., 2010). Referred to as the "ego-depletion" effect, this phenomenon has generated a substantial amount of debate within the literature. While such meta-analytical evidence provides support (Dang, 2017; Hagger et al., 2010), the existence and/or true size of the effect has been questioned with Registered Replication Reports and meta-analyses failing to demonstrate support for the ego-depletion effect (e.g., Carter et al., 2015; Dang, 2018; Hagger et al., 2016; Vohs et al., 2021). Furthermore, while some of the meta-analyses (e.g., Carter et al., 2015;

Hagger et al., 2010) included studies with physical outcomes, they did not carry out a sub-group analysis that explored the size of the depletion effect on different types of physical tasks, which has recently been suggested to influence the size of the effect (Graham & Brown, 2021). In addition, the multi-lab replication studies (e.g., Dang et al., 2021; Hagger et al., 2016) did not involve a physical task as the outcome measure. As a result, domain-specific carryover effects on subsequent physical performance cannot be ruled out. Therefore, more domain specific research is necessary to understand the true effect that prior self-control exertion has on subsequent physical task performance, and how this may be different across different physical performance task types.

Despite the ongoing controversy surrounding the ego-depletion effect, several theoretical models have been established to explain why self-control failures are seen in a multitude of performance contexts, including sport and exercise settings. The first of these, *the strength model of self-control*, implies that individuals possess a limited central resource of self-control, which can become depleted following a period of self-control exertion (Baumeister, Vohs, & Tice, 2007). Although this 'limited resource' perspective has received empirical and meta-analytical support (e.g., Dang, 2017; Hagger et al., 2010), it has also been challenged by evidence demonstrating that performance decrements following prior self-control exertion are not observable when participants were adequately motivated, using techniques such as providing monetary incentives (Brown & Bray, 2017a, Muraven & Slessareva, 2003) and offering choice (Moller, Deci & Ryan, 2006). Consequently, doubts have arisen that self-control failure can be attributed to a single universal resource that becomes depleted (Inzlicht & Friese, 2019).

An alternative explanation is *the shifting priorities model* (Inzlicht & Schmeichel. 2016; Milyavskaya & Inzlicht, 2017); which suggests that initial self-control exertion results in a shift in attentional and motivational foci, whereby the desire to exert additional self-control to achieve distal goals (i.e., optimal performance) is reduced, while the desire to concede to the tempting proximal goal (i.e., reducing discomfort) is increased (Taylor, Boat & Murphy, 2018). These tenants are also consistent with the *opportunity-cost conceptualizations* of self-control, whereby individuals weigh the benefits of pursuing a specific task against its costs (Kurzban, Duckworth, Kable & Myers, 2013; Wolff & Martarelli, 2020).

To provide empirical support for the theoretical models of self-control researchers have typically implemented the 'sequential-task paradigm' to examine the effects of self-control exertion on a subsequent, assumedly unrelated task, also requiring self-control (Baumeister, Vohs & Tice, 2007). Within this paradigm, the experimental (self-control exertion) condition requires participants to complete two tasks necessitating self-control. Conversely, the control (non-self-control exertion) condition requires participants to exert self-control only during the second performance task. The self-control tasks that are frequently employed require participants to resist impulses or temptations created by instinctive and well-learned responses (Arber et al., 2017; Baumeister et al., 2007). For example, self-control is often manipulated using a Stroop task (e.g., Boat & Taylor, 2017; Englert & Wolff, 2015). In the self-control exertion condition, participants complete an incongruent Stroop task where the aim of the task is to select the font color (requiring well-learned responses to be overridden); whereas in the non-self-control exertion condition, participants instead complete a congruent Stroop task (requiring no overriding of well-learned responses). Both versions of the Stroop task involve a central stimulus word (always a color) being presented to participants. Participants are required to select the font color instead of the word itself. In the congruent Stroop task, the target word, and the font color will be matched (e.g., “blue” written in a blue font). In the incongruent Stroop task, the target word and font color will be mis-matched (e.g., “blue” written in red font), thus requiring the inhibition of well-learned dominant responses.

The detrimental effects of self-control exertion on subsequent physical task performance have been substantiated during endurance cycling tasks (Englert & Wolff, 2015; Boat, Taylor, & Hulston, 2017), skill-based tasks (e.g., Darts; McEwan, Ginis & Bray, 2013; Basketball; Englert, Bertrams, Furley & Oudejans, 2015) and simple physical persistence tasks (e.g., wall-sit task; Boat & Taylor, 2017; handgrip task; Bray, Graham, Ginis & Hicks, 2012; sit-up task; Dorris, Power, & Kenefick, 2012). This has been corroborated by recent meta-analytical evidence demonstrating that prior self-control exertion impairs subsequent physical performance (Brown et al., 2020; Giboin & Wolff, 2019). However, it is important to note that these previous meta-analyses have combined studies examining the effects of self-control exertion and mental fatigue on subsequent physical performance, despite suggestions that there are clear differences between these two constructs (Englert, 2016, 2019). For example, tasks that are utilized to induce mental fatigue typically last considerably longer (e.g., 90 minutes AX-continuous performance task; Marcora, Staiano & Manning, 2009) than the tasks that are employed in self-control exertion research (e.g., 4-minute Stroop task; Boat, Williamson, Read, Jeong, & Cooper, 2021). Therefore, it has been argued that typical self-control depletion tasks are not long enough to induce subjective feelings of effort and mental fatigue (Pageaux, Marcora & Lepers, 2013). However, other researchers have suggested that ego-depletion may be a brief manifestation of mental fatigue (Inzlicht & Berkman, 2015) and brief, but more effortful cognitive manipulations can promote equivalent levels of mental fatigue to the traditional longer manipulations (Brown & Bray, 2017; Brown & Bray, 2019). Moreover, self-control exertion and mental fatigue both evidently lead to performance decrements, which may be a result of an unwillingness to employ further effort rather than incapacity (Englert, 2017; Hockey, 2013; Inzlicht & Schmiechel, 2012) and may be overcome with adequate task-motivation (Muraven & Slessareva, 2003). There may also be similarities in the mechanistic underpinnings of self-control and mental fatigue. For example, theories of self-control (e.g., Inzlicht & Schmeichel. 2016; Kurzban et al., 2013; Milyavskaya & Inzlicht, 2017) and the *psychobiological model of fatigue* (Marcora, 2008; Marcora, Bosio & de Morree, 2008; Marcora et al., 2009; Marcora & Staiano, 2010) highlight aspects of motivation as a key mechanism underpinning exercise tolerance. However, the mechanisms specific to self-control, or mental fatigue, have never been collated and analyzed under a meta-analytical lens.

Understanding the mechanisms underpinning the effects of self-control exertion on subsequent physical performance is important to allow for a more complete understanding of *how* and *why* self-control exertion affects performance, and to allow the development of specific targeted interventions aimed at attenuating the effects. The mechanisms that have been proposed to date derive from the two key theories of self-control previously mentioned, yet evidence for these mechanisms is limited and discordant. For instance, support for *the shifting priorities model* has been demonstrated with suggestions that differences in initial perceptions of pain and motivation provide quantifiable shifts in motivational and attentional foci to explain self-control failures (e.g., Boat, Hunte, Welsh, Dunn, Treadwell & Cooper, 2020). Conversely, measurements of motivation, emotion, and attention did not mediate the relationship between self-control exertion and physical task performance (e.g., Stocker et al., 2020). Using a meta-analytical lens to provide a consensus regarding which proposed mechanisms of self-control failure appear to be associated with subsequent reductions in physical performance after completing a self-control exertion task lasting 30 minutes or less, would provide some clarity on this important issue.

Therefore, the aim of this present study is two-fold. Firstly, we will provide a comprehensive meta-analysis of the effects of self-control exertion on subsequent physical performance. This will include an examination of key moderating variables such as study design and physical performance task type, to explore methodological factors that may influence the reported effects of self-control exertion on physical performance. Secondly, we will adopt a meta-analytical approach to examine the mechanisms underpinning the effects of self-control exertion on subsequent physical performance.

Methods

The PRISMA guidelines on protocols and reporting in systematic reviews and meta-analyses were followed (Moher, Liberati, Tetzlaff, Altman & Prisma Group, 2009). A full overview of the checklist can be found with the additional material (see Appendix 1).

Eligibility Criteria

Studies published prior to June 2021 (the month selected to conclude the systematic search) were considered for review. Studies had to be performed on healthy humans and written in English. Studies also had to utilize the sequential task paradigm in which participants engaged in two consecutive tasks (Baumeister et al., 2007). In the self-control exertion condition, there was the necessity that studies included a cognitive exertion task that has been shown to deplete self-control by requiring well-learned responses to be overridden (e.g., incongruent Stroop task, transcription task with instruction to omit letters). In the control condition, it was essential that self-control was not exerted in the first task, with tasks employed not requiring any overriding of well-learned responses (e.g., congruent Stroop task, transcription task with no additional instructions). For clarity, the common cognitive exertion tasks that were employed in the included studies were: (i) incongruent Stroop task; (ii) transcribing tasks; (iii) solving hard labyrinths; (iv) regulating emotions while watching an emotion-based video clip. In an attempt to focus solely on studies examining self-control exertion, the duration of the initial exertion task was required to be less than 30 minutes, as this duration is typically associated with self-control exertion studies (e.g., Boat et al., 2020; Englert & Wolff, 2015; Wagstaff, 2014), whereas cognitive manipulations exceeding 30 minutes in duration are suggested to elicit mental fatigue (e.g., Marcora et al., 2009). Therefore, in the present meta-analysis we focused only on self-control tasks 30 minutes or less in duration.

In accordance with the sequential-task paradigm, performance tasks had to require self-control and be objective measures of physical performance (e.g., handgrip task, cycling time trial). Outcome performance tasks were split into four categories: (i) isometric: outcomes included holding a posture or producing maximal force for as long as possible; (ii) aerobic: outcomes involved any type of endurance activity, namely covering a given distance in as short a time as possible, or covering as much distance or generating as much work as possible until volitional exhaustion; (iii) dynamic: outcomes involved completing as many repetitions of a particular movement, in a given time or until volitional exhaustion/failure; (iv) motor skill performance: outcomes involved measures such as number of false starts and reaction times/accuracy on skill-based tasks. Once studies met the above criteria, they were also assessed to see if they measured any potential mechanisms underpinning the effects of self-control exertion on subsequent physical performance.

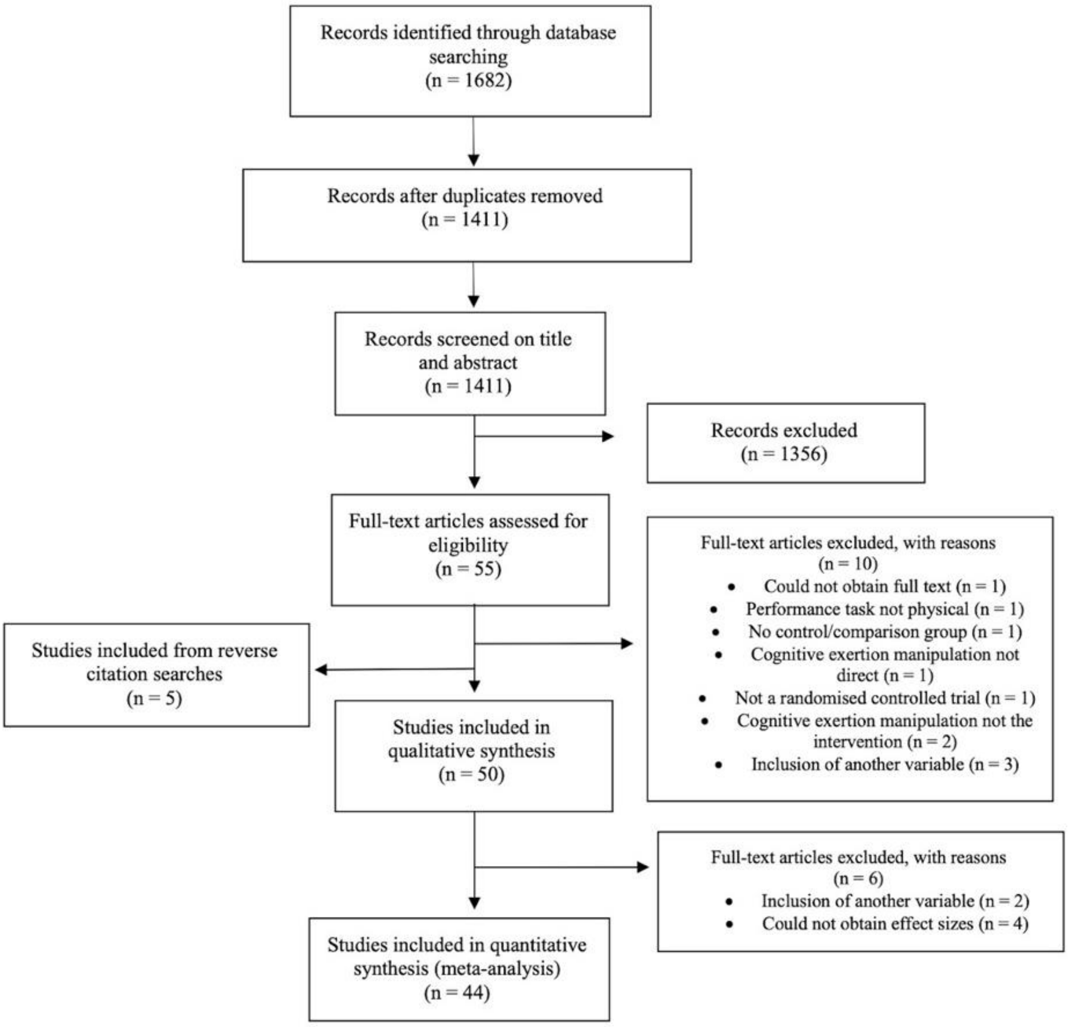
All relevant statistical information to calculate effect sizes was required for all studies. The Cochrane Handbook (Higgins et al., 2019) was used to follow protocols surrounding missing data (e.g., using data from previous studies to impute missing standard deviations; Furukawa et al., 2006). A full breakdown of methods used can be found in the Data Synthesis section. In addition, missing data from eligible studies was also requested by contacting the corresponding authors. If these protocols could not be implemented or missing data was not received from authors, studies were excluded.

Search Strategy and Study Selection

A systematic review of the literature was carried out using Science Direct (n = 213), Web of Science (n = 749), PubMed (n = 119) and SPORTDiscuss (n = 576). To find relevant publications, searches were conducted with the following keywords search: '(self-control OR ego-depletion) AND (physical OR task OR activity OR endurance OR exercise OR skill OR exert)'. This search resulted in 1,682 publications which was reduced to 1,411 once duplicates were removed (search concluded June 2021). Publications were screened for eligibility from their title and abstract, resulting in 55 papers being selected for a full text review. An additional reverse citation search produced 5 additional papers to be included. The full text review led to an additional 16 papers being excluded due to not fully meeting the eligibility criteria. Forty-four articles were included in the meta-analysis, producing 50 comparisons for the effects of self-control exertion on subsequent physical performance. Furthermore, these studies provided 61 comparisons for the exploration of the mechanisms underpinning the effects of self-control exertion on subsequent physical performance (see Figure 2.1 for PRISMA flow diagram).

Figure 2.1

PRISMA study selection flowchart (Moher et al., 2009).



Data Extraction

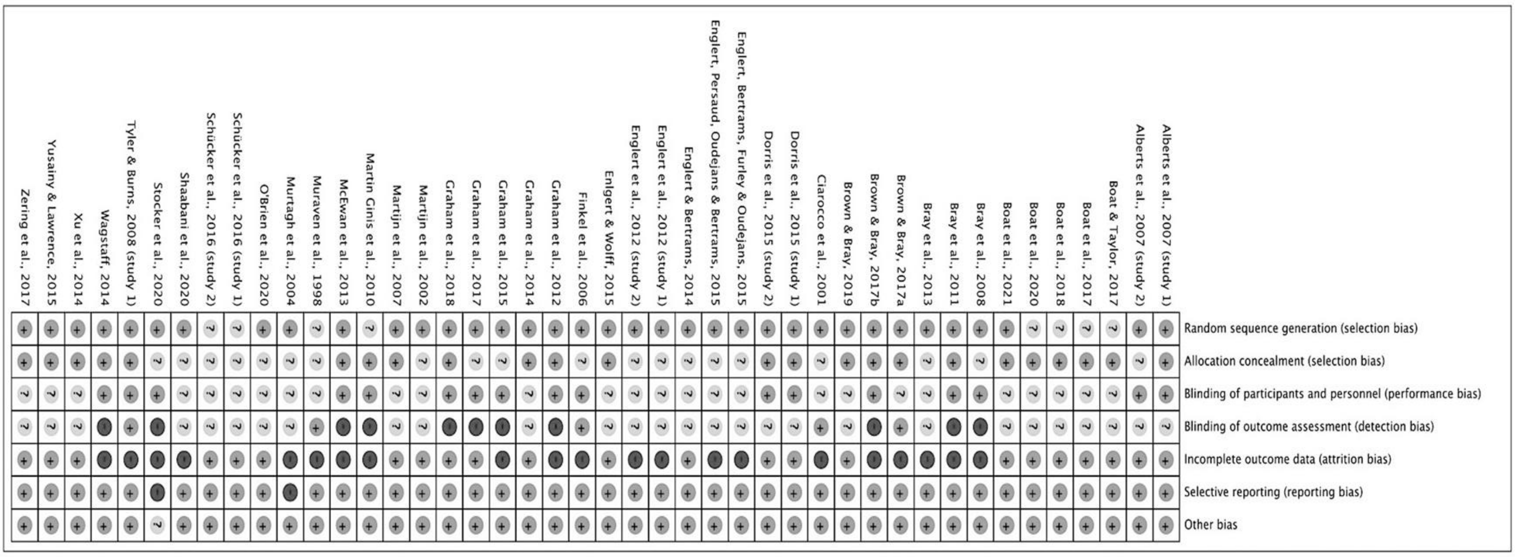
Data including sample characteristics (e.g., participant demographic and number) and study characteristics (e.g., depletion task used, study design) were collated, alongside means and standard deviations for measures of physical performance and the underpinning mechanisms. The mechanisms that provided a substantial amount of data (at least 3 effect sizes; Valentine, Pigott & Rothstein, 2010) were pain (split by overall pain, pain at the start of the physical performance task, and pain at the end of the physical performance task), motivation, self-efficacy, and ratings of perceived exertion (RPE). For all variables, if the data were presented graphically, numerical data were attained using ImageJ (ImageJ 1.53v, NIH, Bethesda, MD, USA).

Risk of Bias

The risk of bias for each publication was assessed by three reviewers independently, using the risk bias tool in Review Manager (RevMan 5.4; The Cochrane Collaboration, 2020) (https://tech.cochrane.org/revman) software. Across five domains (selection bias, performance bias, detection bias, attrition bias and reporting bias) publications were labelled as “low risk”, “unclear risk” or “high risk”. Where there was disagreement, a consensus was achieved through discussions (see Figure 2.2 for risk of bias assessment).

Figure 2.2

Summary of risk of bias assessment of the included studies. Key: ‘+’ low risk, ‘-’ high risk, ‘?’ unclear risk.



Data Synthesis

Hedge’s *g* effect sizes were calculated to summarize estimates of effect, calculated using standard procedures ($M_1 – M_2 / SD_{\text{pooled}}$) (Higgins et al., 2019). For the handful of studies that used handgrip tasks as a performance outcome, Hedge’s *g* was calculated using provided change scores (i.e., effect sizes were calculated using the difference of performance before and after the cognitive manipulation was administered) to enhance the precision of effect size estimation (Higgins et al., 2019). Two studies (Graham et al., 2017; McEwan et al., 2013) provided multiple effect sizes for one physical performance outcome; following the Cochrane Handbook recommendations (Higgins et al., 2019) these outcomes were combined using the RevMan 5.4 calculator to produce a single pair-wise comparison. Two studies (Boat et al., 2020; Brown & Bray, 2017b) provided multiple effect sizes over several time points.

To avoid a unit-of-analysis error (i.e., double counting), the control group participant sample was shared across the pairwise comparisons (Higgins et al., 2019). Two studies (Brown & Bray, 2017b; Ciarocco et al., 2001) did not provide sufficient standard deviation data to calculate the necessary effect sizes; as per recommendations (Furukawa et al., 2006; Higgins et al., 2019) an average of standard deviations was taken from similar handgrip studies included in the meta-analysis (Alberts, Martijn, Greb, Merckelbach & de Vries, 2007; Bray, Martin Ginis, Hicks, & Woodgate, 2008; Bray, Oliver, Graham, & Martin Ginis, 2013; Graham & Bray, 2012; Graham & Bray, 2015) to impute estimated standard deviations (*SD self-control depletion condition* = 17.49 s; *SD control condition* = 23.71 s). Five studies (Alberts et al., 2007; Brown & Bray, 2017a; Brown & Bray, 2019; Shaabani et al., 2020; Yusainy & Lawrence, 2015) included a secondary experimental manipulation (e.g., persistence priming vs. neutral priming; mindfulness intervention vs. no mindfulness intervention), in this instance only the data from the condition that did not involve the secondary manipulation were included (i.e., high self-control exertion & neutral condition compared to low self-control exertion & neutral condition). Similar protocols were followed for the investigation into the mechanisms. To calculate one single effect size for the 'overall pain' subgroup, the start of task pain and end of task pain effect sizes provided in four studies were combined (Boat & Taylor, 2017; Boat et al., 2018; Boat et al., 2020; Boat et al., 2021). These effect sizes were also analyzed independently. Seven studies provided two or more effect sizes for measures of motivation (Boat et al., 2018; Boat et al., 2020; Boat et al., 2021; Brown et al., 2017; Brown & Bray, 2019; Graham & Bray, 2015; Stocker et al., 2020). Similarly, these were combined to align with recommendations (Higgins et al., 2019).

Meta-analysis

All analyses were conducted using RevMan 5.4. Due to the varied methods of data collection, a random effects model was used. Firstly, a comprehensive meta-analysis of the effects of self-control exertion on subsequent physical performance was performed, including an examination of key moderating variables such as study design and physical performance task type. Heterogeneity was explored using the Cochrane Q (x^2) test and summarized with the I^2 statistic. Sensitivity analysis was conducted by removing one study at a time to analyse its influence on the overall effect size (see Appendix 2). Subsequently, a separate meta-analysis was conducted to examine the mechanisms underpinning the effects of self-control exertion on subsequent physical performance.

Results

Included Studies

Forty-four articles provided a total of 50 comparisons with 2315 participants (not adjusted for within-subject designs) (see Figure 2.3). Study characteristics and outcomes are outlined in Table 2.1.

Figure 2.3

Forest plot of the studies examining the effects of prior self-control exertion on physical task performance.

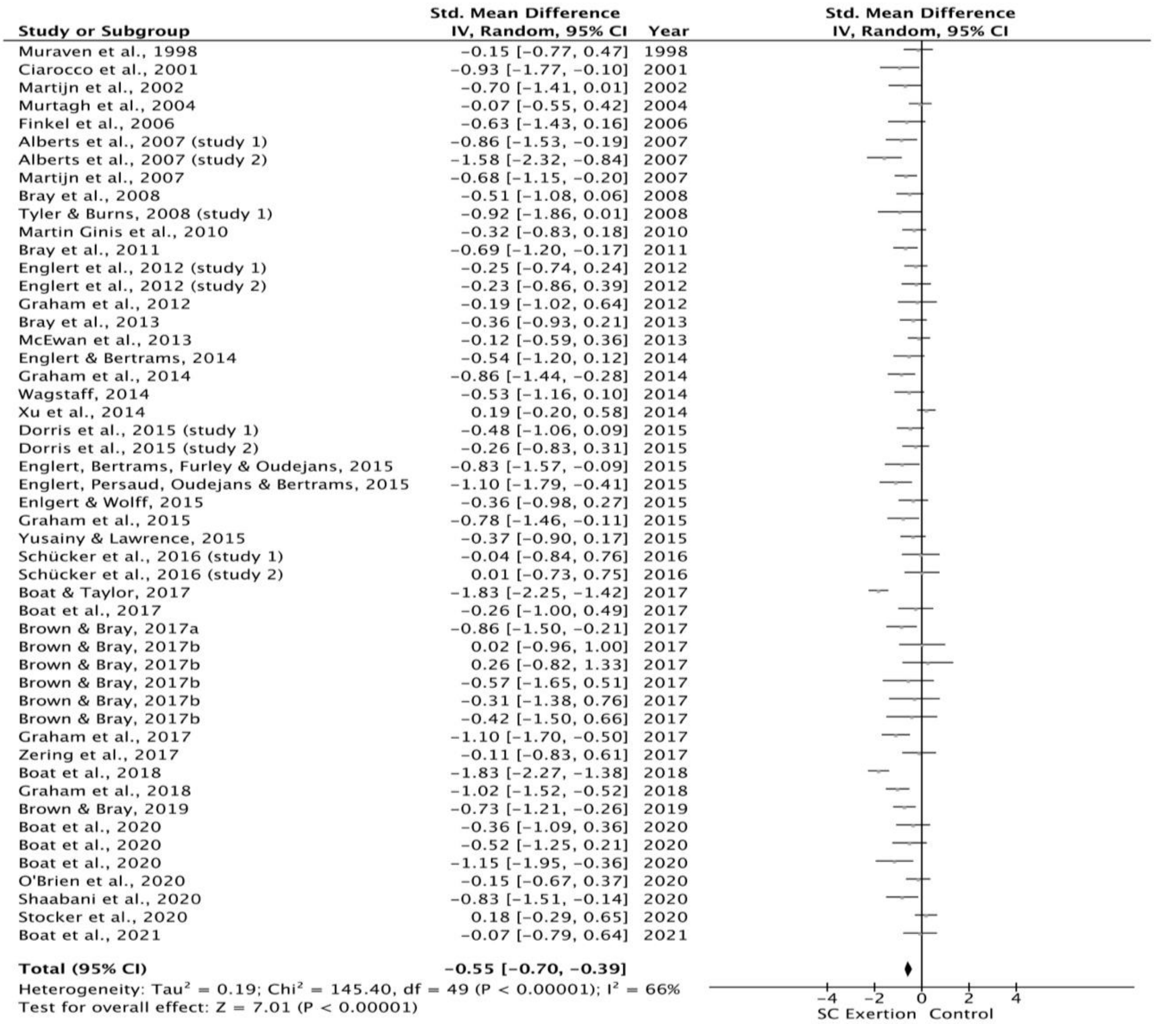


Table 2.1

Study Characteristics and Outcomes

Study	Participants	N	N (control)	Design	Cognitive Task	Control Task	Cognitive Task Duration	Performance Task	Main effect on performance	Mechanism(s) assessed
Muraven, Tice & Baumeister, 1998 (Muraven et al., 1998) study 1	University students	20	20	Between	Regulate emotions while watching emotion-based video clip	Watching the same video clip with no emotion regulation instructions	3 min	Handgrip TTE	Time to failure decreased	-
Ciarocco, Sommer & Baumeister, 2001, (Ciarocco et al., 2001)	University students (recreationally active)	12	12	Between	Ostracism condition	Conversation condition	3 min	Handgrip TTE	Time to failure decreased	-
Martjin et al., 2002 (Martijn et al., 2002)	University students	17	16	Between	Regulate emotions while watching emotion-based video clip	Watching the same video clip with no emotion regulation instructions	3 min	Handgrip TTE	Time to failure decreased	-

Murtagh & Todd (Murtagh & Todd, 2004)	University students	42	27	Between	Incongruent Stroop task	Congruent Stroop task	15 min	Handgrip TTE	No significant difference in time to failure	-
Finkel et al., 2006 (Finkel et al., 2006)	University students	13	13	Between	Inefficient social coordination	Efficient social coordination	6 min	Handgrip TTE	Time to failure decreased	-
Alberts, Martijn, Greb, Merckelbach, & de Vries, 2007, (Alberts et al., 2007) study 1	University students (recreationally active)	19	19	Between	Solving hard labyrinths	Solving easy labyrinths	10 min	Handgrip TTE	Time to failure decreased	-
Alberts, Martijn, Greb, Merckelbach, & de Vries, 2007, (Alberts et al., 2007) study 2	University students (recreationally active)	19	19	Between	Calculating difficult sums + video distraction	Calculating easy sums + no video distraction	8 min	Holding a 1.5-kg weight TTE	Time to failure decreased	-
Martijn et al., 2007 (Martijn et al., 2007)	University Students	37	36	Between	Solving hard labyrinths	Solving easy labyrinths	10 min	Handgrip TTE	Time to failure decreased	-
Bray, Martin Ginis, Hicks, & Woodgate, 2008, (Bray et al., 2008)	University students (sedentary)	26	23	Between	Incongruent Stroop task	Congruent Stroop task	3 min 40 sec	Handgrip TTE (isometric) + Handgrip maximum voluntary contraction (anaerobic)	Time to failure decreased (Isometric)	EMG activation; RPE

									No significant change in peak force (anaerobic)	
Tyler & Burns, 2008 (Tyler & Burns, 2008)	University students	10	10	Between	Arithmetic while standing on one leg	Counting backwards from 2000 in 5’s while standing on both feet	6 min	Handgrip TTE	Time to failure decreased	-
Martin Ginis, & Bray, 2010, (Martin Ginis & Bray, 2010)	University students (recreationally active)	31	30	Between	Incongruent Stroop task	Congruent Stroop task	3 min 40 sec	10 min cycling	Decrease in exercise work output (kilojoules)	-
Bray, Ginis, & Woodgate, 2011, (Bray et al., 2011)	Older adults	33	28	Between	Incongruent Stroop task	Congruent Stroop task	3 min 40 sec	Handgrip TTE	Time to failure decreased	-
Dorris, Power, & Kenefick, 2012, (Dorris et al., 2012) study 1	Highly trained and experienced college athletes	24		Within	Counting backwards from 1000 in 7’s + holding a spirit level	Counting backwards from 1000 in 5’s	Not standardized (till counting finished)	Press Ups	Less press up reps completed	-
Dorris, Power, & Kenefick, 2012, (Dorris et al., 2012) study 2	Highly trained and experienced college athletes	24		Within	Counting backwards from 1000 in 7’s +	Counting backwards from 1000 in 5’s	Not standardized (till counting finished)	Sit Ups	Less sit up reps completed	-

					holding a spirit level					
Englert, & Bertrams, 2012, (Englert & Bertrams, 2012) study 1	Experienced male basketball players	32	32	Between	Transcribing task	Transcribing task (no instructions to omit letters)	6 min	Basketball Free throws	No significant difference in free throw success rate /10	-
Englert, & Bertrams, 2012, (Englert & Bertrams, 2012) study 2	Experienced male basketball players	21	19	Between	Transcribing task (instructions to omit letters)	Transcribing task (no instructions to omit letters)	6 min	Dart Throwing	No significant difference in throwing accuracy	-
Graham, & Bray, 2012 (Graham & Bray, 2012)	University students (recreationally active)	15	9	Between	Guided imagery	Quite rest	6 min	Handgrip TTE	No significant difference in time to failure	-
Bray, Oliver, Graham, & Martin Ginis, 2013, (Bray et al., 2013)	University students (recreationally active)	24	24	Between	Incongruent Stroop task	Congruent Stroop task	5 min	Handgrip TTE	Time to failure decreased	-
McEwan, Ginis, & Bray, 2013 (McEwan et al., 2013)	Young adults, inexperienced dart players	31	31	Between	Incongruent Stroop task	Congruent Stroop task	5 min	Dart Throwing	Reduced throwing accuracy	-

									No significant difference in reaction time	
Englert & Bertrams, 2014 (Englert & Bertrams, 2014)	University students (with sprinting experience)	18	19	Between	Transcribing task (instructions to omit letters)	Transcribing task (no instructions to omit letters)	6 min	Sprint start (reaction time recorded)	Increased reaction time	-
Graham, Sonne & Bray, 2014 (Graham et al., 2014)	University students	25	25	Between	Imagery	Quiet rest	3 min	Handgrip TTE	Time to failure decreased	-
Wagstaff, 2014, (Wagstaff, 2014)	Experienced cyclists	20		Within	Regulate emotions while watching emotion-based video clip	Watching the same video clip with no emotion regulation instructions	3 min	Cycling 10 km	Increased completion time	RPE
Xu et al., 2014 (Xu et al., 2014)	Community adults and young adults	51		Within	Transcribing task (crossing out letters task)	Transcribing task (only ask to omit the letter ‘e’)	8 min	Handgrip TTE	No significant difference in time to failure	-
Englert, Bertrams, Furley, & Oudejans, 2015, (Englert et al., 2015)	Experienced male basketball players	16	15	Between	Transcribing task (instructions to omit letters)	Transcribing task (no instructions to omit letters)	6 min	Basketball free throws	Decrease in free throw success rate	-

Englert, Persaud, Oudejans, & Bertrams, 2015, (Englert et al., 2015)	Experienced female soccer players	19	19	Between	Transcribing task (instructions to omit letters)	Transcribing task (no instructions to omit letters)	6 min	Sprint starts	Increase in false starts	-
Englert & Wolff, 2015, (Englert & Wolf, 2015)	University students	20		Within	Incongruent Stroop task	Congruent Stroop task	Time to complete 80 trials (time not reported)	Cycle as fast as possible for 18 min at fixed workload	Reduced bpm and rpm	RPE
Graham, & Bray, 2015, (Graham & Bray, 2015)	University students (recreationally active)	19	18	Between	Incongruent Stroop task	Congruent Stroop task	5 min	Handgrip TTE	Time to failure decreased	Motivation; Self-efficacy; RPE; Arousal
Yusainy & Lawrence, 2015 (Yusainy & Lawrence, 2015)	Young adults	27	28	Between	Attentional control task	Attentional control task (with no instructions)	6 min	Handgrip TTE	Time to failure decreased	-
Schücker & MacMahon, 2016 (Schücker & MacMahon, 2016) study 1	Trained athletes	12		Within	Incongruent Stroop task	Congruent Stroop task	10 min	Beep test	No significant difference in completion time	-

Schücker & MacMahon, 2016 (Schücker & MacMahon, 2016) study 2	Trained athletes	14		Within	Incongruent Stroop task	Congruent Stroop task	10 min	Beep test	No significant difference in completion time	-
Boat & Taylor, 2017, (Boat & Taylor, 2017)	Young people (recreationally active)	63		Within	Incongruent Stroop task	Congruent Stroop task	4 min	Wall-sit	Time to failure decreased	Perceptions of Pain
Boat, Taylor, & Hulston, 2017, (Boat et al., 2017)	Experienced cyclists	14		Within	Incongruent Stroop task	Congruent Stroop task	4 min	Cycling 16 km	Increased completion time	Glucose
Brown & Bray, 2017, (Brown & Bray, 2017a)	University students (recreationally active)	20	21	Between	Incongruent Stroop task	Documentary	10 min	Handgrip TTE	Reduced time to failure	Motivation, EMG activation, RPE
Brown & Bray, 2017, (Brown & Bray, 2017b)	University students (recreationally active)	123	21/20, 20,21,21,21	Between	Incongruent Stroop task	Documentary	0,2,4,6,8,10 min	Handgrip TTE	Reduced time to failure	Motivation; Self-efficacy; RPE
Graham, Martin Ginis, & Bray, 2017, (Graham et al., 2017)	University students (recreationally active)	25	25	Between	Incongruent Stroop task	Congruent Stroop task	5 min	Bench Press & Leg Extension	Reduced repetitions for both bench press & leg extensions	Motivation; Self-efficacy; RPE

Zering, Brown, Graham, & Bray, 2017, (Zering et al., 2017)	Young people (recreationally active)	15		Within	Stop-signal task	Documentary	10 min	Cycling (graded exercise test)	Reduced peak power (Watts)	RPE
Boat, Atkins, Davenport, & Cooper, 2018 (Boat et al., 2018)	Young people (recreationally active)	55		Within	Incongruent Stroop task	Congruent Stroop task	4 min	Wall-sit	Reduced time to failure	Perceptions of Motivation and Pain
Graham, Li, Bray, & Cairney, 2018, (Graham et al., 2018)	Children	33	37	Between	Incongruent Stroop task	Congruent Stroop task	1 min	Handgrip TTE	Reduced time to failure	Motivation
Brown & Bray, 2019 (Brown & Bray, 2019)	University students	36		Within	Incongruent Stroop task	Documentary	10 min	Cycling (work completed in 20 min)	Decrease in total work	Motivation, RPE, Goal commitment, Heart rate biofeedback
Boat et al., 2020 (Boat et al., 2020)	University students (recreationally active)	29		Within	Incongruent Stroop task	Congruent Stroop task	4, 8, 16 min	Wall-sit	Reduced time to failure	Perceptions of Motivation and Pain
O'Brien, Parker, Moore, & Fryer, 2020, (O'Brien et al., 2020)	University students (recreationally active)	29		Within	Transcribing task (instructions to omit letters)	Transcribing task (no instructions to omit letters)	6 min	Handgrip TTE	No significant difference in time to failure	Challenge and threat states; Cerebral perfusion
Shaabani, Naderi, Borella & Calmeiro, 2020 (Shaabani et al., 2020)	Male basketball players	18	18	Between	Modified Stroop Task	No intervention/task	15 min	Basketball free throws	Decrease in free throw success rate	-

Stocker, Seiler, Schmid, & Englert, 2020 (Stocker et al., 2020)	University students	34	34	Between	Transcribing task (instructions to omit letters)	Transcribing task (no instructions to omit letters)	6 min	Bicep Endurance task	No significant difference in time to failure	Motivation, Emotion, Attention
Boat et al., 2021 (Boat et al., 2021)	Male cyclists (recreationally trained)	15		Within	Incongruent Stroop task	Congruent Stroop task	4 min	10 km cycling time-trials	No significant difference in overall performance time	Perceptions of Motivation and Pain, RPE

TTE time to exhaustion, km kilometres, EMG electromyography, RPE rating of perceived exertion, BPM beats per minute, RPM revolutions per minute a `–` in the ‘mechanism(s) assessed’ column indicates that no mechanisms were assessed in the relevant study.

Risk of Bias

A summary of the risk of bias for each included study is presented in Figure 2.2. All studies were rated as low risk for selective reporting as all relevant information was considered present. Twenty-three out of 44 were rated high-risk in at least one domain. A rating of high risk or unclear risk was commonly a result of a lack of allocation concealment (selection bias) and blinding protocols (performance and detection bias) being employed. In addition, studies often reported incomplete outcome data (attrition bias).

Meta-analyses

***Overall Effect*.** Results showed that 44 of the 50 comparisons resulted in a negative effect of self-control exertion on physical task performance (see Figure 2.3). Overall, a significant medium negative effect of prior self-control exertion on physical task performance was found (g = -0.55 [-0.70, -0.39], Z = 7.01, $p < 0.001$). Heterogeneity analysis demonstrated significant heterogeneity for the overall effect ($Q(49) = 145.40$, $p < 0.001$, T^2 = 0.19, I^2 = 66), therefore, the decision to conduct subgroup analyses examining the factors that could impact the effect was justified (see Figure 2.3).

Results of the sensitivity analyses (see Appendix 2) revealed a stable significant effect size ranging from g = -0.53 [-0.67, -0.40] (when excluding the study by Boat & Taylor, 2017) to g = -0.59 [-0.74, -0.44] (when excluding the study by Xu et al., 2014).

Study Design. Studies that implemented a within-subject design demonstrated a similar significant medium negative effect of self-control exertion on physical task performance (g = -0.53 [-0.87, -0.20], Z = 3.13, p = 0.002), when compared to studies that implemented a between-subject design (g = -0.54 [-0.68, -0.40], Z = 7.40, $p < 0.001$) (see Figure 2.4a).

There was significant heterogeneity in terms of study design for publications that employed a within-subjects design ($Q(17) = 95.50$, $p < 0.001$, $T^2 = 0.42$, $I^2 = 82$), and between-subjects design ($Q(31) = 48.85$, $p = 0.02$, $T^2 = 0.06$, $I^2 = 37$).

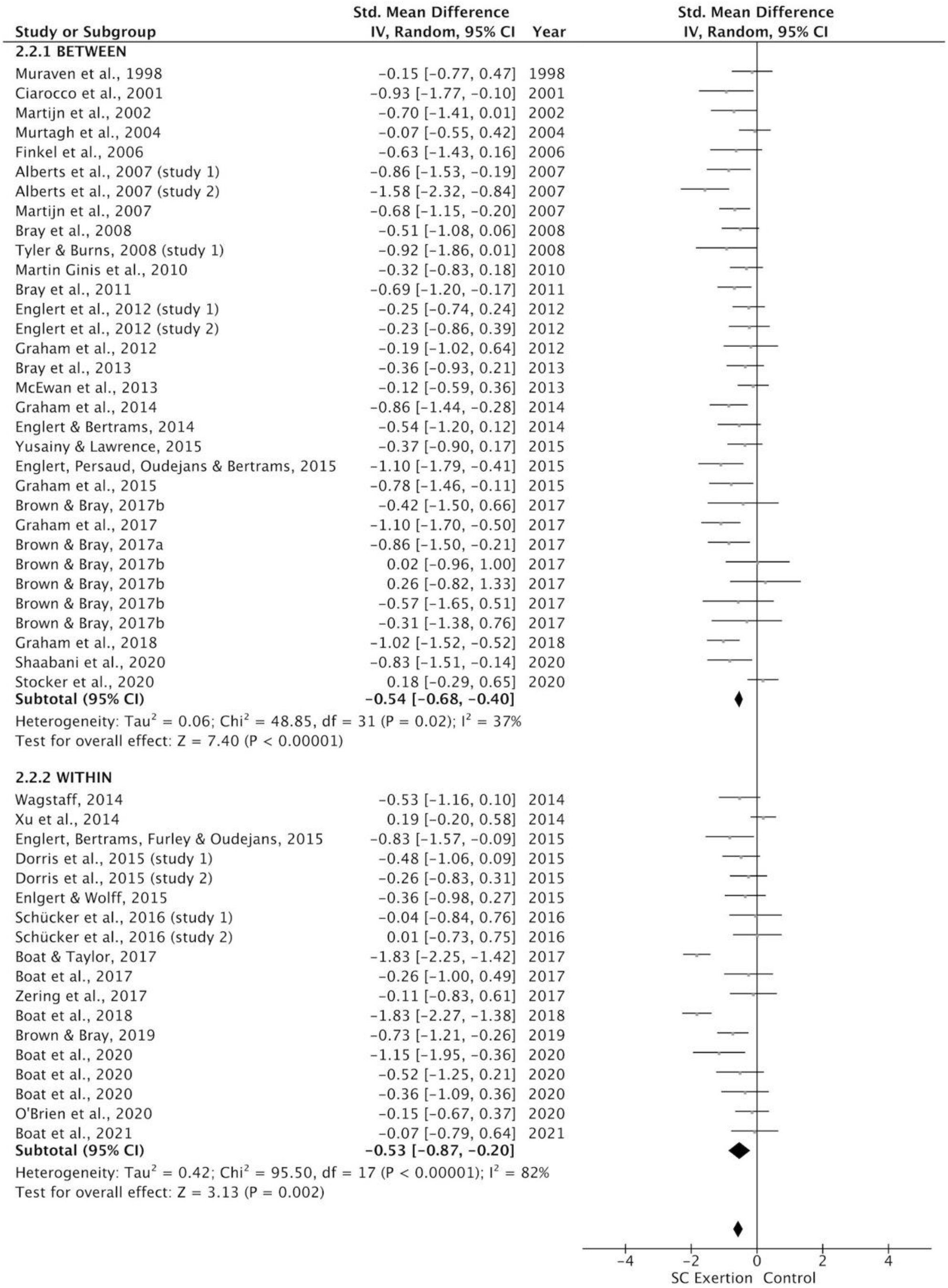
Type of Physical Performance Task. The subgroup analysis demonstrated a significant negative effect of self-control exertion on physical task performance for all physical task types. The largest negative effect was found for isometric physical tasks (g = -0.62 [-0.84, -0.39], Z = 5.32, $p < 0.001$). A large negative effect size was also found for dynamic physical tasks (g = -0.61 [-1.09, -0.12], Z = 2.44, p = 0.01), while smaller negative effect sizes were found for studies that implemented aerobic (g = -0.36 [-0.58, -0.14], Z =

3.19, $p = 0.001$) and motor skill ($g = -0.45$ [-0.71, -0.20], $Z = 3.47$, $p < 0.001$) tasks (see Figure 2.4b).

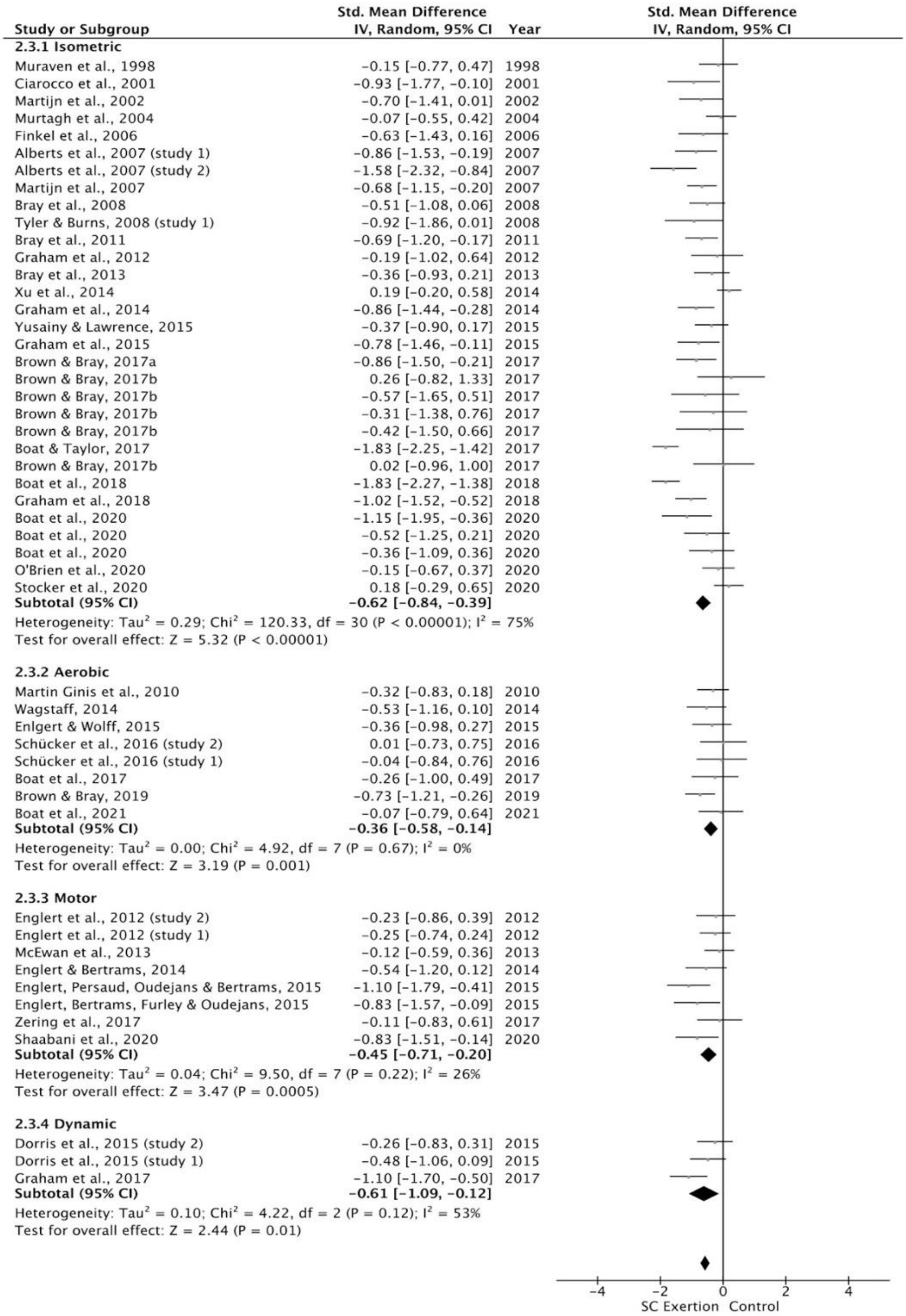
There was significant heterogeneity in terms of type of physical performance task for studies that employed an isometric physical performance task ($Q(30) = 120.33$, $p < 0.001$, $T^2 = 0.29$, $I^2 = 75$). Heterogeneity was not observed in studies that employed aerobic ($Q(7) = 4.92$, $p = 0.67$, $T^2 = 0.00$, $I^2 = 0$), motor skill ($Q(7) = 9.50$, $p = 0.22$, $T^2 = 0.04$, $I^2 = 26$) or dynamic ($Q(2) = 4.22$, $p = 0.12$, $T^2 = 0.10$, $I^2 = 53$) physical performance tasks.

Figure 2.4

Forest plots displaying the results of the subgroup analysis of the effects of prior self-control exertion on physical performance (Figure 4a: Study design; Figure 4b: Performance task type).



Note: Figure 2.4a. Study design.



Note: Figure 2.4b. Performance task type.

Mechanisms Analyses

Pain. There was no statistically significant effect of self-control exertion on participants' overall perceptions of pain (g = 0.08 [-0.08, 0.24], Z = 1.01, p = 0.31) (see Figure 2.5a). However, there was a statistically significant small effect of self-control exertion on participants' initial perceptions of pain (g = 0.18 [0.02, 0.34], Z = 2.18, p = 0.03), whereby initial perceptions of pain tended to be higher following self-control exertion (see

Figure 2.5b). There was no statistically significant effect of self-control exertion on participants' perceptions of pain at the end of the physical task (g = -0.03 [0.19, -0.13], Z = 0.31, p = 0.75) (see Figure 2.5c). Heterogeneity was not observed for any of the pain subgroups (overall pain, p = 1.00; initial pain, p = 0.56; end pain, p = 0.45).

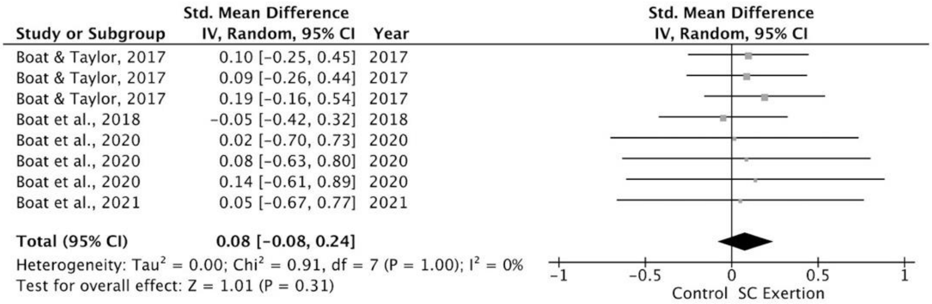
Motivation. There was no statistically significant effect of self-control exertion on participants' motivation (g = -0.03 [-0.36, 0.29]) Z = 0.20, p = 0.84). Significant heterogeneity was observed for the effects on motivation (Q(15) = 56.46, p < 0.001, T^2 = 0.30, I^2 = 73).

Self-efficacy. There was a statistically significant medium negative effect of self-control exertion on self-efficacy (g = -0.48 [-0.86, -0.10], Z = 2.47, p = 0.01), whereby participants displayed lower levels of self-efficacy following self-control exertion, compared to the control group/condition (see Figure 2.5e). Significant heterogeneity was observed for the effects on self-efficacy (Q(8) = 15.64, p = 0.05, T^2 = 0.16, I^2 = 49).

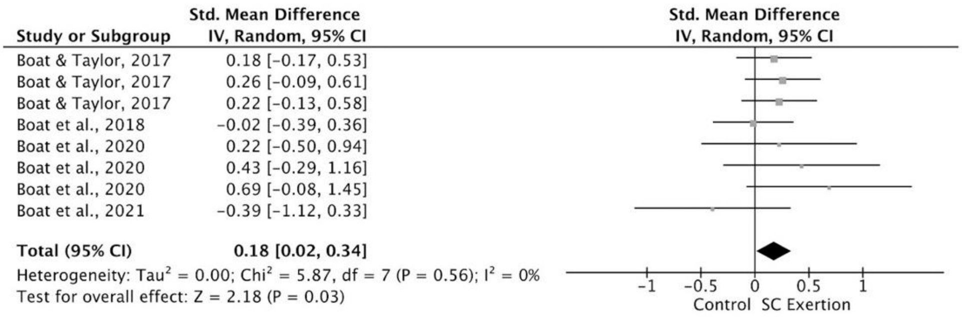
RPE. There was no statistically significant effect of self-control exertion on participants' RPE (g = 0.03 [-0.25, 0.32], Z = 0.21, p = 0.83) (see Figure 2.5f). Significant heterogeneity was observed for the effects on RPE (Q(11) = 19.59, p = 0.05, T^2 = 0.10, I^2 = 44).

Figure 2.5

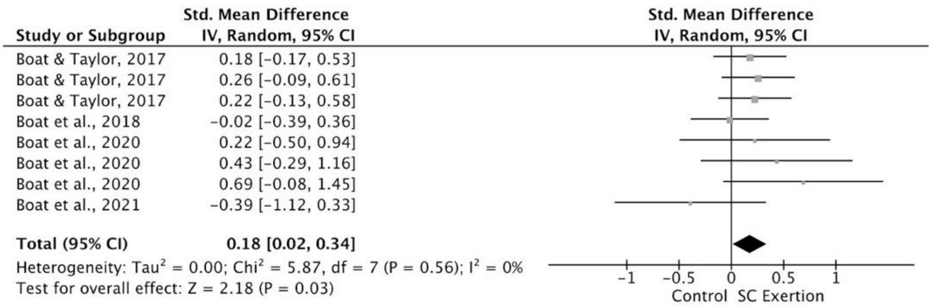
Forest plots examining the mechanisms for the effects of prior self-control exertion on physical performance (Figure 5a: Overall pain; Figure 5b: Start pain; Figure 5c: End pain; Figure 5d: Motivation; Figure 5e: Self-efficacy; Figure 5f: RPE).



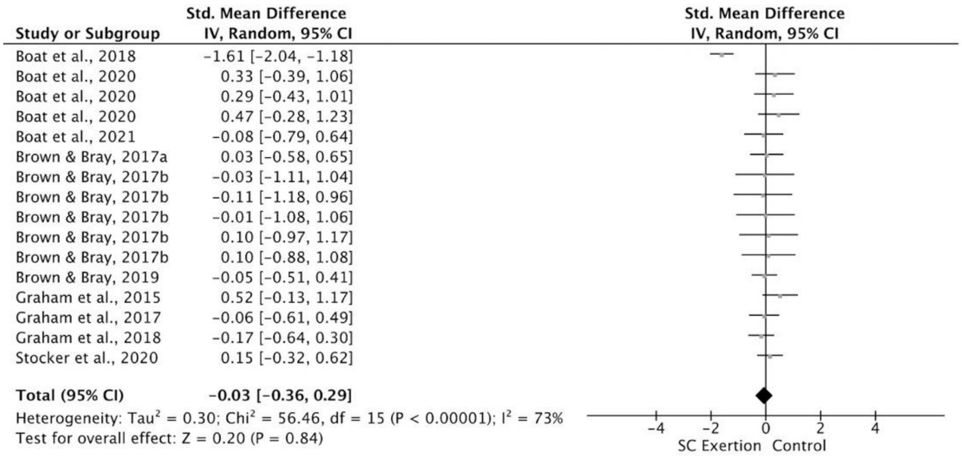
Note: Figure 2.5a: *Overall pain*



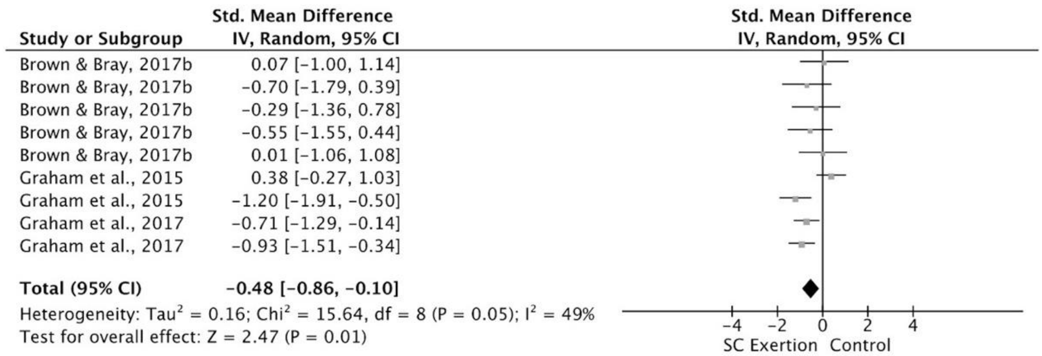
Note: Figure 2.5b: *Start pain*



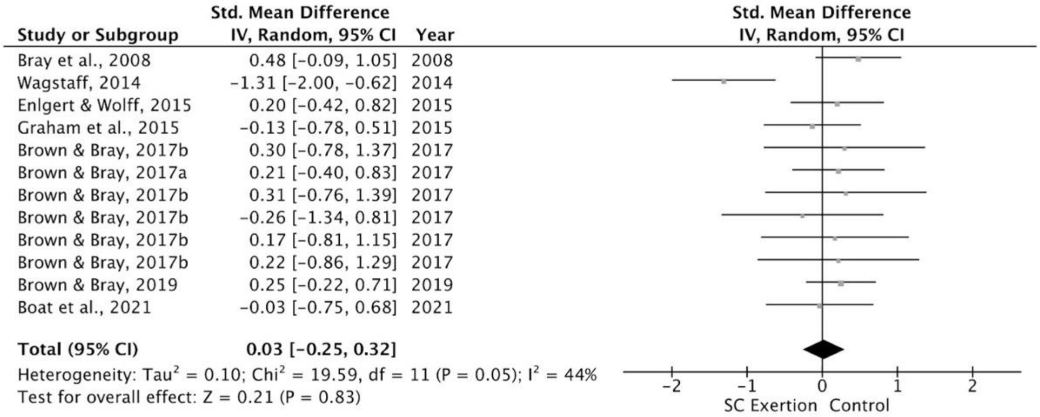
Note: Figure 2.5c: *End pain*



Note: Figure 2.5d: *Motivation*



Note: Figure 2.5e: *Self-efficacy*



Note: Figure 2.5f: *RPE*

Discussion

The findings of the present study suggest that the prior exertion of self-control resulted in a statistically significant medium sized negative effect on subsequent physical task performance (*g* = -0.55). Subgroup analyses revealed a statistically significant medium sized negative effect for studies employing both a within-subject design (*g* = -0.53) and a between-subject design (*g* = -0.54). Furthermore, the type of physical performance task also influenced the results, with prior self-control exertion demonstrating a medium-to-large sized negative effect on isometric (*g* = -0.62) and dynamic (*g* = -0.61) based physical tasks, while a small-to-medium sized negative effect was found for studies that utilized aerobic (*g* = -0.36) and motor skill (*g* = -0.45) tasks. In addition, the present study is the first to meta-analytically examine the mechanisms underpinning the effects of self-control exertion on subsequent physical performance. The findings demonstrated that the prior exertion of self-control had a medium-sized negative effect on self-efficacy (*g* = -0.48), and a small effect on initial perceptions of pain during the subsequent physical task (*g* = 0.18); while there was no statistically significant effect of prior self-control exertion on perceptions of pain overall (*g* = 0.08), pain in the latter stages of the physical performance task (*g* = -0.03), motivation (*g* = -0.03) or RPE (*g* = 0.03). The findings provide novel evidence for self-efficacy and initial perceptions of pain to be recognized as the mechanisms by which prior self-control exertion affects subsequent physical performance.

An important finding of the present study is that prior self-control exertion had a statistically significant medium sized negative effect on subsequent physical performance (*g* = -0.55). This finding extends a recent meta-analysis which combined studies examining both prior self-control exertion and mental fatigue studies (Brown et al., 2020). For comparison, previously obtained meta-analysed effects sizes when combining both self-control exertion and mental fatigue studies and for studies with a duration of less than 30 minutes for the initial cognitive task were somewhat smaller (g = -0.38 and g = -0.45, respectively; Brown et al., 2020). The differences between the effect sizes could be attributed to the inclusion of unpublished studies in the meta-analysis of Brown et al. (2020), therefore, greater influence of the ‘file drawer effect’, in which null effect sizes may reduce the overall effect size.

Another key finding of the present study was that studies that employed a within-subject design produced a similar medium negative effect size (g = -0.53) to studies employing a between-subject design (g = -0.54). Previous meta-analytical evidence has displayed larger effect sizes for studies that have employed a between-subjects design (Brown et al., 2020). Subsequently, the inclusion of more recent studies in the present meta-analysis, most of which employ a within-subjects design, could explain the discrepancy with previous findings.

The findings of the present study also suggest that the type of physical task used is another important factor to consider when interpreting studies examining the effects of prior self-control exertion on subsequent physical performance. Specifically, the present meta-analysis demonstrated a medium-to-large negative effect for isometric (g = -0.62) and dynamic (g = -0.61) physical tasks, while small-to-medium negative effect sizes were found for aerobic (g = -0.36) and motor skill (g = -0.45) physical tasks. However, the discrepancies between physical task type subgroups may be confounded by study design. For example, 20 out of 31 studies that employed an isometric task utilized between-subjects study designs, which typical yield larger effect sizes (e.g., Alberts et al., 2007; Brown & Bray, 2017a). Furthermore, some effect sizes in the present meta-analysis are derived from a low number of studies (e.g., dynamic subgroup n = 3). Nonetheless, these findings support the notion that prior cognitive exertion has a greater detrimental effect on subsequent physical performance in isometric tasks (e.g., wall-sit), compared to whole-body endurance tasks (e.g., cycling) (Giboin & Wolff, 2019). The varying physiological and psychological demands of different performance tasks could explain the differences in effects seen in the present study. For instance, isometric performance tasks such as a wall-sit may demand greater levels of attentional control for optimal performance compared to whole-body endurance tasks, such as cycling, that rely on more automatic motor processes (Dimitrijevic, Gerasimenko, & Pinter, 1998; Giboin & Wolff, 2019). Therefore, future research should continue to investigate the effects of self-control exertion on differing physical performance tasks to advance this debate; and consider examining sport-specific performance tasks with ecological validity for real-world sporting performance.

A key novel aspect of the present study is the meta-analytical investigation of the mechanisms that underpin the effects of self-control exertion on subsequent physical performance. The largest effect size was found for self-efficacy, with a statistically significant medium-sized negative effect (g = -0.48). As a result of initial self-control exertion, individuals may have reduced belief that they possess the capabilities to mobilize the resources required to exert further self-control, which would be required to achieve optimal performance on a subsequent physical task (Bandura, 1977; Graham & Bray, 2015). In accordance with the *opportunity-cost conceptualization* of self-control (Kurzban et al., 2013; Wolff & Martarelli, 2020), following prior self-control exertion individuals may be less motivated to exert further self-control if they do not feel confident that they can persevere at the task and if they do not see any additional benefit in investing further self-control and effort. This will result in the cons of persisting at the task (i.e., feelings of pain and discomfort) outweighing the benefits (i.e., optimal performance), and could lead to reduced physical performance and/or the termination of effort (Inzlicht, Shenhav & Olivola, 2018; Kool & Botvinick, 2014; Kurzban et al., 2013). Acknowledging self-efficacy as a key mechanism for physical task performance could have valuable implications for sport and exercise practitioners. Specifically, athletes and those in their support network should be aware of the impact that prior self-control exertion can have on the athlete's self-efficacy for a subsequent physical task. Moreover, researchers should develop specific interventions that aim to increase self-efficacy to combat the negative effects of prior self-control exertion on subsequent performance.

Prior self-control exertion was also discovered to have a small-sized negative effect on individuals' initial perception of pain during a physical performance task (g = 0.18). However, there was no effect on overall pain (g = 0.08) or pain towards the end of a physical performance task (g = -0.03). These findings are in accordance with previous research suggesting that the prior exertion of self-control results in elevated perceptions of pain, but only during the early stages of a physical task (e.g., Boat & Taylor, 2017; Boat et al., 2020). Theoretically, the importance of perceptions of pain can be explained by *the shifting priorities model* (Inzlicht & Schmeichel. 2016; Milyavskaya & Inzlicht, 2017) and *opportunity-cost conceptualization* (Kurzban et al., 2013; Wolff & Martarelli, 2020) of self-control. Specifically, it is suggested that the prior exertion of self-control causes increased perceptions of pain during the early stages of a subsequent physical performance task, causing an individuals' attention during the task to shift to the proximal goal (e.g., ceasing exercise to alleviate pain) and away from the distal goal (e.g., optimal physical performance); ultimately causing a reduction in subsequent physical performance. The present study has investigated this using a meta-analytical approach for the first time.

In the present study, there was no effect of prior self-control exertion on individual's motivation (g = -0.03). This finding is in accordance with previous research showing motivation did not change in response to cognitive exertion (e.g., Brown & Bray, 2017b; Brown & Bray, 2019; Graham et al., 2015). The current findings present challenges for the motivational aspect of *the shifting priorities model* (Inzlicht & Schmeichel. 2016; Milyavskaya & Inzlicht, 2017), as this meta-analysis suggests that there is no effect of prior self-control exertion on subsequent motivation during the subsequent physical task. Interestingly, changes in other more nuanced aspects of motivation, such as goal commitment and exercise intentions, have been suggested to decrease following prior self-control exertion (Brown & Bray, 2019). However, the evidence base is very limited and thus requires further investigation. Such research is necessary to examine multiple aspects of motivation to provide a more detailed explanation of an individual's motivational intentions, than the more commonly used broad measures of task and intrinsic motivation. In addition, it has been suggested that future research should aim to investigate more complex motivational processes through qualitative methods (i.e., think aloud) to record the reasons behind changes to individuals' intentions or commitment (Brown & Bray, 2019; Marcora, 2008; Marcora et al., 2008, 2009; Marcora & Staiano, 2010). Moreover, an explanation for the findings of the present study could be a result of motivation being measured at varied time-points in the included studies. Some research has measured motivation at pre-selected intervals throughout the physical task (e.g., Boat et al., 2018), while other studies have acquired a singular measurement prior to the physical task (e.g., Graham et al., 2018). These inconsistencies could explain the discrepant findings of previous research, and future studies should continue to examine the time course of the changes in multiple aspects of motivation as a result of the prior exertion of self-control.

The findings of this meta-analysis provide very limited evidence for RPE to be considered a mechanism that could underpin the effects of prior self-control exertion on subsequent physical performance (g = 0.03). RPE, however, has been considered as the main explanatory mechanism underpinning the effects of mental fatigue on subsequent physical performance (Pageaux & Lepers, 2018; Van Cutsem et al., 2017). Taken together, these findings allude to there being key differences between the constructs of self-control exertion and mental fatigue. Our findings support the notion that typical self-control depletion tasks are not long enough to induce subjective feelings of effort (Pageaux, 2013), and thus self-control depletion tasks may not invoke the same mechanistic responses that underpin the effects of mental fatigue on subsequent physical performance. Therefore, caution should be taken when combining both research streams for future investigation as results may not be attributed to the same mechanisms. Furthermore, RPE findings are difficult to interpret as both self-control exertion and mental fatigue result in individuals reducing the absolute intensity that they are exercising at. Thus, RPE measurements may be comparable to participants in a non-depleted/non-fatigued state, while the absolute exercise intensity would be different, resulting in differences in performance but no differences in RPE (Pageaux, 2014; Van Cutsem et al., 2017). Further research is required to fully uncouple the relationship between RPE following cognitive exertion and physical performance and how this may be different for studies that induce mental fatigue and those that require self-control exertion.

Limitations and Future Direction

Although yielding novel findings surrounding the effects of self-control exertion on physical task performance, some limitations must be addressed. It must be acknowledged that the findings of this study only relied on published literature and no research teams were contacted regarding unpublished papers. We decided to base our meta-analysis on published literature only, that was accessible to the scientific community, and that we were confident had been through the peer-review process. However, we acknowledge that the omission of unpublished work may skew the present effect sizes and conceal the impact of the 'file-drawer' effect, with the omission of studies that reported null effects. Moreover, the risk of bias assessment could not identify any study included in the meta-analysis as completely low risk. Factors associated with higher risks were namely associated with detection bias and attrition bias. For example, several studies did not provide information surrounding the blinding of researchers, and thus future studies should encourage and explicitly state the use of double-blind techniques. In addition, researchers must openly report the reasons and handling of incomplete data outcomes to safeguard the internal validity of studies.

Furthermore, while the present study has provided the first meta-analysis on the mechanisms that are affected by prior self-control exertion, it must be noted that some findings were interpreted from a low number of effect sizes due to the limited evidence base.

The significance level of an effect size can be influenced considerably by the inclusion of an additional publication when dealing with effect sizes calculated from a relatively small number of comparisons. Therefore, further research into the mechanisms identified in this meta-analysis is required to create an extensive and stronger evidence base. Finally, future mediational research is required to investigate the relationship of the 'causal chain' between self-control exertion, the mechanisms identified in this meta-analysis, and subsequent physical performance. This will develop our understanding of how these mechanisms are impacted by prior self-control exertion, and as a result how they impact subsequent physical performance. Building upon the findings of this meta-analysis, future research should aim to create interventions that target the suggested mechanisms, to identify strategies to attenuate the effects of self-control exertion on subsequent physical performance. For example, researchers could develop strategies to alter perceptions of pain in the initial stages of a physical task. Such strategies could reduce the initial perception of pain, resulting in individuals being able to continue exerting the self-control required to achieve optimal performance.

Moreover, some additional mechanisms could not be included in the meta-analysis due to a lack of empirical evidence. For example, state anxiety could not be included as a potential mechanism because the studies that have examined this have included an additional direct manipulation of state-anxiety and thus have not solely measured the effects on self-control exertion on state anxiety in isolation (Englert & Bertrams, 2012; Englert et al., 2015). Similarly, motivational incentives (Brown & Bray, 2017a), biofeedback (Brown & Bray, 2019) and autonomy supportive instructions (Graham et al., 2014) have been employed to attenuate the depletion effect, and should be further investigated to provide valuable insight into the potential role of specific aspects of motivation. Furthermore, more recently, it has been hypothesized that feelings of boredom may be provoked once self-control has been exerted (Wolff & Martarelli, 2020); yet no empirical studies have investigated this to date. Therefore, task-induced boredom should be examined as a psychological factor that may explain performance reductions on physical tasks following self-control exertion.

Conclusion

Results from the current meta-analysis showed that 50 comparisons (and over 2200 participants) resulted in a medium negative effect (g = -0.55) of prior self-control exertion on subsequent task performance. Explanatory mechanisms that underpin the effect were also established, whereby self-efficacy was lower and initial perceptions of pain were higher, following the prior exertion of self-control. Future research should continue to mechanistically investigate the effects of prior self-control exertion on subsequent physical performance. Ultimately, this knowledge can be used to design and implement interventions aimed at attenuating the effects of self-control exertion, to enhance physical task performance.

Chapter Three

Prior self-control exertion and repeated running sprint performance

Abstract

The exertion of self-control has been associated with impaired performance on several subsequent physical tasks also requiring self-control. However, it remains unknown whether repeated running sprint exercise performance is negatively affected by the prior exertion of self-control. Therefore, this study explored whether prior self-control exertion reduces subsequent performance on a repeated running sprint task and potential mechanisms for these effects. Nineteen physically active males (24.3±3.8 y) completed a repeated running sprint task on two occasions. The repeated sprint exercise task involved 5 x 6 s sprints, with a 24 s active recovery between each sprint. Prior to the repeated running sprint task, participants completed a congruent Stroop task (non-self-control exertion) or an incongruent Stroop task (self-control exertion) for 4 min. Participant's perception of pain, motivation, and RPE (measured via a 1–20-point scale) were recorded following each print. Repeated measures ANOVA (self-control * repeated sprint) revealed that mean peak power (p = 0.47) and average speed (p = 0.86) were unaffected by self-control exertion. However, there was a significant main effect of self-control for peak power (p = 0.05), whereby peak power was higher in the self-control exertion trial (630 ± 112 W, 95% CI: 572 – 688 W) compared to non-self-control exertion condition (606 ± 120 W, 95% CI: 544 – 667 W). Furthermore, there was no significant interaction for perceptions of pain (p = 0.11) or RPE (p = 0.92). However, there was a significant main effect for overall motivation (p = 0.03), whereby motivation was lower in the self-control exertion condition (12.06 ± 3.66, 95% CI: 10.30 – 13.83) when compared to the non-self-control condition (12.96 ± 3.24, 95% CI: 11.41 – 14.53). Finally, there was no difference in percentage fatigue, heart rate, or blood lactate concentration following self-control exertion (all p > 0.05). The findings suggest that prior self-control exertion leads to reduced motivation during a repeated running sprint task. In addition, self-control exertion may result in higher peak power output during a repeated running sprint task. Overall, despite reduced motivation, there seems to be no negative effect of prior self-control exertion on subsequent repeated running sprint exercise performance.

Key words: self-control; sprint; motivation; pain; cognitive exertion

Introduction

Self-control refers to one's ability to exert control over their thoughts, emotions, and behaviors (Baumeister, Vohs & Tice, 2007; Graham & Brown, 2020). Exhibiting high levels of self-control has been linked with a range of beneficial behavioral outcomes such as improved wellbeing, enhanced academic achievement, and better interpersonal relationships (de Ridder, van der Weiden, Gillebaart, Benjamins & Fekke Ybema, 2020). More specifically, high levels of self-control are advantageous to successful physical activity behavior (Englert, 2016, 2017). For instance, athletes require self-control to succeed in endurance based physical tasks that require working at high intensities for prolonged periods of time. They must resist discomfort and the temptation to reduce effort, and instead invest sustained effort to produce optimal performance (Boat, Williamson, Read, Jeong, Cooper, 2021; Taylor, Boat & Murphy, 2018).

Self-control capacity can differ between individuals (i.e., trait self-control), as well as across situations within the same individual (i.e., state self-control) (Gailliot, Gitter, Baker & Baumeister, 2012; Tangney, Baumeister & Boone, 2004). Regarding state self-control, it has been suggested that there are limited resources available for an individual to repeatedly exert self-control. These resources are susceptible to depletion when regulating behavior over a prolonged period (Baumeister et al., 2007). This state is commonly known as "ego-depletion" (Baumeister, Bratslavsky, Muraven & Tice, 1998). According to this *strength model of self-control* perspective, once in this depleted state, an individual's ability to employ additional self-control is reduced, resulting in performance decrements on subsequent acts of self-control (Baumeister et al., 2007; Hagger, Wood, Stiff & Chatzisarantis, 2010). Although the *strength model of self-control* has gained empirical and meta-analytical support (e.g., Dang, 2018; Hagger et al., 2010), recent reviews and replication studies have criticized the validity of the strength model (e.g., Kurzban, 2010; Carter, Kofler, Forster, & McCullough, 2015; Wolff, Baumann & Englert, 2018). For instance, researchers have struggled to identify the single universal resource that can become depleted (Inzlicht & Friese, 2019). In addition, previous research has shown that when individuals were provided with monetary incentives (Brown & Bray, 2017), meditated (Friese, Messner & Schaffner, 2012) or offered choice (Moller et al., 2006), performance was not impaired following an initial exertion of self-control. As a result, there have been concerns as to whether a depleted self-control resource is responsible for subsequent self-control failures (Inzlicht & Friese, 2019). Alternatively, *the shifting priorities model* has been suggested (Inzlicht, Schmeichel & Macrae, 2014; Inzlicht

& Schmeichel, 2016; Milyavskaya & Inzlicht, 2017). The assumption of this model is that shifts in attention and motivation drive reductions in performance on subsequent tasks, following an initial task requiring self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017). As a result, individuals pursue proximal temptations (e.g., reducing discomfort) and seek alternative behaviors (e.g., quitting a wall-sit task) (Boat & Taylor, 2017). Assumptions of this model are also aligned with the *opportunity-costs conceptualization* of self-control, whereby the benefit of pursuing a specific task is weighed up against its cost (Kurzban et al., 2013; Wolff & Martarelli, 2020).

Notwithstanding the ongoing theoretical debates, it has been widely documented that an initial exertion of self-control results in performance decrements on a subsequent physical task also requiring self-control (e.g., Boat, Atkins, Davenport & Cooper, 2018; Boat et al., 2020; Boat et al., 2021; Bray, Oliver, Graham & Martin Ginis, 2013; Englert & Wolff, 2015; O'Brien, Parker, Moore & Fryer, 2020; Wagstaff, 2014). Recent meta-analytical evidence has found small-to-medium ($g = -0.45$; Brown et al., 2020; $g = 0.55$; Chapter Two; $d = -0.506$; Giboin & Wolff, 2019) negative effects of prior self-control exertion on subsequent physical task performance. However, the existence of the depletion effect has been doubted (Carter et al., 2015; Wolff, Baumann & Englert 2018), with some research failing to replicate the effect (Hagger & Chatzisarantis, 2016; Stocker, Seiler, Schmid & Englert, 2020). As a result, it has been suggested that publication bias may have led to an overestimation of the effect (Carter et al., 2015; Wolff, Baumann & Englert 2018).

Developing on this literature and to address the replication crisis, there has been a movement towards improving the ecological validity of self-control exertion research, to formulate conclusions regarding more complex sport performance. Recent meta-analytical research has demonstrated negative depletion effects for a number of subsequent effort-based physical tasks including endurance performance ($g = -0.36$), skill-based tasks ($g = -0.45$) and isometric tasks ($g = -0.62$) (Chapter Two). While these studies provide valuable insight into the effects of prior self-control exertion on subsequent effort-based performance, it is not currently known whether self-control exertion impairs repeated running sprint performance. Athletes are frequently required to continually reproduce maximal and near maximal sprints with short periods of recovery over an extended period (Dawson et al. 1997; Bishop et al. 2001). In addition, success in intermittent sports is commonly linked to the ability to perform repeated bouts of high-intensity sprint exercise (Saunders, Sale, Harris & Sunderland, 2014). As a result, to achieve optimal repeated sprint performance (and subsequently sporting performance), it could be suggested that athletes may require self-control to invest sustained effort and resist discomfort and the temptation to reduce effort during a repeated sprint task (Boat et al., 2021; Taylor et al., 2018). Therefore, a key novel aim of the current study will be to investigate the potential for prior self-control exertion to impact repeated spring performance.

Furthermore, the underpinning mechanisms that can explain the effects of self-control exertion on subsequent exercise performance remain unclear. Aligned with the tenants of *the shifting priorities model* (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), perceptions of pain, motivation, and ratings of perceived exertion (RPE) have all been suggested as possible underpinning mechanisms of the effect (e.g., Boat et al., 2018; Boat et al., 2020; Wagstaff, 2014; Wolff, Bieleke, Stähler, Schüler, 2020; Wolff & Martarelli, 2020). Currently, perceptions of pain (predominantly during the initial stages of physical tasks) seem to be the most plausible mechanism (Chapter Two). However, due to a lack of empirical research and inconsistencies in results, further evidence is required for mechanisms such as motivation and RPE, before conclusions can be drawn (Chapter Two). With regards to perceptions of pain and motivation, it has been suggested that an initial exertion of self-control results in increased perceptions of pain and reduced motivation, due to shifts in foci towards proximal temptations (e.g., alleviating pain) and seeking alternative behaviors (e.g., quitting a wall-sit task) (Boat et al., 2018; Boat et al., 2020). As self-control is exerted, individuals may choose to weigh up the costs (e.g., pain) and benefits (e.g., optimal performance) of the physical task and begin to seek behavioral alternatives (e.g., quitting a wall-sit task) (Bieleke, Barton, & Wolff, 2021; Kurzban et al., 2013; Wolff & Martarelli, 2020). Moreover, individual's RPE has been investigated as a potential underpinning mechanism, whereby perceptions of perceived exertion are higher following the exertion of self-control (e.g., Wagstaff, 2014). However, the literature regarding the effects of self-control exertion on RPE is limited and often inconsistent (Chapter Two). Consequently, further examination of perceptions of pain, motivation, and RPE is warranted to strengthen the evidence base regarding how self-control exertion effects subsequent physical performance.

Therefore, the aims of the current study were to determine: a) whether exerting self-control affects repeated sprint performance; and b) whether perceptions of pain, motivation, and RPE are mechanisms that may explain the performance effects. Considering the extensive self-control literature (e.g., Boat et al., 2020; Boat et al., 2021; Brown et al., 2020;

Wagstaff, 2014), it was hypothesized that prior self-control exertion on a cognitively demanding task (i.e., incongruent Stroop task) would result in reduced repeated sprint performance (hypothesis 1), as well as increased perceptions of pain and RPE, and reduced motivation (hypothesis 2) during the repeated sprint task compared to a control condition (i.e., congruent Stroop task).

Methods

Participants

The sample consisted of 19 males aged 20-32 years old (24.3 ± 3.8 years). Participants all reported that they were recreationally active, exercising on average 4 days (*SD* = 1 day) per week. A University approved general health questionnaire determined all participants as healthy (see Appendix 3). A power calculation (G*Power version 3.1; Faul et al., 2007) with power = 0.95 and $\alpha = 0.05$, specified a minimum sample size of $N = 19$ would be satisfactory to detect a medium effect size ($d = 0.40$), which is representative of previous self-control studies (Boat et al., 2020; Brown et al., 2020; Giboin & Wolff, 2019).

Procedures

Following approval from a University ethics committee, each participant signed an informed consent form (see Appendix 4) after the study was explained in full and it was described that participation was anonymous and voluntary (see Appendix 5 for participant information sheet). Furthermore, participants were asked to refrain from strenuous exercise and avoid alcohol and caffeine intake 24 h before the start of each laboratory visit. Participants took part in three experimental sessions in total (separated by at least 48 h). The study employed a randomised, order-balanced, single-blind, crossover design. Following one familiarization session, participants completed two main experimental trials (self-control exertion and non-self-control exertion), each separated by at least 48 h.

Experimental Protocol

During the familiarization trial, the experimental protocol and measures were explained to the participants in full and they were provided an opportunity to ask any questions. Following this, participants were provided with an opportunity to practice the cognitive function task (Stoop task) and the repeated sprint protocol (see measures section).

On arrival to the first experimental session, participants were required to complete a daily stress and fatigue questionnaire (see measures section), due to the potential for stress and fatigue to influence the impact of self-control exertion on subsequent physical performance (Englert & Rummel, 2016; Graham, Martin Ginis & Bray, 2017; Tangney et al., 2004). Participants then provided a baseline capillary blood sample, for the determination of blood lactate concentration (see measures section). Following these baseline measurements, participants completed a standardized 5 min warm-up, consisting of walking (3 min) and running at 10 km·h^{-1} (2 min). Following this, participants were then required to complete a self-control exertion task (incongruent Stroop task) or a non-self-control exertion task (congruent Stroop task) for 4 min. A modified Stroop task (Stroop, 1935) was used as the experimental manipulation in this study. This task is a well-established self-control task and has been successfully applied in previous self-control research (Boat et al., 2020; Boat et al., 2021). In addition, employing the Stroop task for 4 min has previously been shown to produce negative effects on subsequent physical performance (e.g., Boat et al., 2018).

In the Stroop task, a word (always a color) was displayed in the center of a computer screen, and participants were required to select the colored response pad button that matched the color of the print ink. In the congruent version of the Stroop task (non-self-control exertion), the word and color were matched (e.g., the word "yellow" was printed in yellow ink). In the incongruent version of the Stroop task (self-control exertion), the printed text and print ink color were mismatched. For example, if the word "yellow" was printed in red ink, the correct keypad response would be the red button. The incongruent version of the Stroop task has frequently been shown to be a cognitively challenging task that requires self-control, whereby participants are required to volitionally overrule their initial impulse to select the ink color, as opposed to the word (e.g., Boat et al., 2020; Englert & Wolff, 2015; McEwan et al., 2013). The Stroop task was completed on a laptop computer, with a head-to-monitor distance of 80–100 cm, via custom-made software (SuperLab 6.0) with words serially presented on the screen. Participants were instructed to respond as accurately and quickly as possible. Stimuli remained on the screen until participants responded. There was an inter-stimulus interval of 1 s. Prior to the actual test, participants completed a practice session lasting 30 s to familiarize themselves with the task and response pad. Immediately following the Stroop task, participants completed a CR-10 Scale (Borg, 1998) as a manipulation check to assess participant's perceived mental effort during the cognitive task.

Immediately following the completion of the questionnaires, participants performed the repeated sprint protocol (see measures section). Just before the first sprint and after each subsequential sprint, participants' perception of pain, motivation, and RPE were recorded (see measures section). Immediately and 5 min following the repeated sprint protocol, participants had a capillary blood sample taken for the determination of blood lactate concentration.

Measures

Daily Stress. Daily stress was assessed using The Daily Inventory of Stressful Events Questionnaire (Almedia, Wethington & Kessler, 2002), comprising of seven statements that asks participants to report whether any number of stressful events had occurred today by circling either "yes" or "no" (e.g., "Anything at work or university that most people would consider stressful"). This questionnaire has been shown to have high internal consistency and predictive validity (Almeida et al., 2002) and has frequently been used to measure daily stress in self-control research (Boat et al, 2021) (see Appendix 6).

Perceptions of Physical Fatigue. The fatigue subscale of the Profile of Mood States questionnaire was modified to assess physical fatigue (i.e., "I feel physically worn out" and "I feel physically exhausted"; McNair, Lorr & Droppleman, 1992). Participants were required to rate their agreement with each item on a five-point scale (1= not at all true; 5 = very true). These items have demonstrated acceptable reliability and high factor loadings in previous research (Boat et al., 2021) (see Appendix 7).

Mental Exertion. To measure participants' mental exertion following the Stroop task, Borg's single-item CR-10 scale (Borg, 1988) was used (0 = extremely weak; 10 = absolute maximum). This questionnaire is frequently used in self-control research (e.g., Boat et al., 2020; Steel, Bishop & Taylor, 2021) and has been shown to be a valid measure (McEwan et al., 2012) (see Appendix 8).

Heart Rate. Heart rate (HR) was measured continuously throughout each of the repeated sprints using a Polar HR monitor (Polar H10, Kempele, Finland) which transmitted continuous HR data to a Polar watch (Polar Unite, Kempele, Finland) where it was recorded. HR measures were taken manually just before the first sprint and after each subsequent sprint.

Blood Lactate Concentration. Capillary blood samples (20 μL) were taken using a Unistik lancet (Unistik 3.0 mm; Owen Munford, Woodstock, United Kingdom) and collected into capillary tubes containing electrolyte balanced heparin (*safe*CLINITUBES, Radiometer, Copenhagan, Denmark), and analyzed immediately (BIOSEN C-line, EKF, London, United Kingdom) for the determination of blood lactate concentration.

Perceptions of Pain and Motivation. Participant's perceptions of pain and motivation were measured on a 1–20-point scale which assessed their current feelings for each item. For instance, participants' perception of pain was measured by responding to the statement "please rate your current level of pain experienced during this sprint" (1 = no pain; 20 = worst possible pain), and participants' motivation was assessed by responding to the statement "please rate how motivated you are for the next upcoming sprint" (1 = I have zero motivation; 20 = I am fully motivated). Due to the demands of the physical task, responses were collected verbally. Comparable single measure-items have previously been used in self-control research to measure perceptions of pain and motivation (Boat et al., 2021; Stocker et al., 2020) (see Appendix 9).

Perceptions of RPE. Participant's RPE was also measured verbally using a 1–20-point Borg scale (1 = no exertion at all; 20 = extremely hard) (Borg, 1998) (see Appendix 9).

Repeated Sprints. The repeated sprint protocol involved five maximal sprints, each 6 s in duration, with 24 s active recovery, performed on a nonmotorized treadmill (Demo-Force, Woodway, USA). Participants were instructed to perform each sprint maximally and were given no verbal encouragement for the duration of every sprint. Participants wore a belt around their waist which was attached to a force transducer. All data were recorded using a modified version of Spike 2 (V7.07, CED, Cambridge). This protocol has previously been employed to measure repeated sprint performance and has demonstrated high levels of reliability (Saunders et al., 2014; Sunderland, Stevens, Everson & Tyler, 2015).

To assess repeated sprint performance, mean power output (MPO; W), peak power output (PPO; W) and average speed ($km{\cdot}h^{-1}$) were recorded for each sprint. In addition, MPO (W) and PPO (W) were used to calculate percentage fatigue for each trial. Percentage fatigue was calculated using recommendations made by Saunders et al. (2014) who suggested the most suitable formulae for determining fatigue during repeated sprint exercise: percentage fatigue = 100-([total power output/ideal power output] X 100),where total power output represents the sum of the power output values for all sprints during the set, and ideal power output represents the number of sprint performance multiplied by the highest power output of all the sprints in the set (Glaister, Howaston, Pattison & McInnes, 2008; Saunders et al., 2014).

Statistical Analysis

All data were analyzed using SPSS (version 25; SPSS Inc., Chicago, IL., USA). To check for baseline differences between stress, fatigue, and mental exertion, paired samples *t*-tests were conducted. Separate paired samples *t*-tests were also conducted to compare Stroop task performance and percentage fatigue between self-control and non-self-control trials. In addition, based upon suggestions within the literature that shifts in attentional and motivational processes are particularly affected during the early stages of a physical performance task (e.g., Boat et al., 2020), additional pairwise comparisons for initial perceptions of pain and motivation (measured after the first sprint) were conducted using paired samples t-tests.

A two-way (self-control: self-control exertion vs. non-self-control exertion; repeated sprint: sprint 1 vs. sprint 2 vs. sprint 3 vs. sprint 4 vs. sprint 5) repeated measures ANOVA was conducted to analyze differences in power output (MPO & PPO; W) and average speed ($km \cdot h^{-1}$). Note that two participants were removed from the repeated sprint task performance analysis due to failed data. Therefore, analysis for power output (MPO & PPO; W) and average speed ($km \cdot h^{-1}$) were conducted on $N = 17$. Subjective scales (perceived pain and motivation) and physiological measures (RPE and heart rate) were also analyzed using a two-way (self-control*repeated sprint) repeated measures ANOVA at each time-point. Furthermore, a two-way (self-control*time) repeated measures ANOVA was used to analyze difference in blood lactate concentrations. All ANOVAs are reported with appropriate Bonferroni adjustments (with corrected *p* values reported). Effect sizes for paired samples *t*-tests were calculated using Cohen's *d* and interpreted in accordance with commonly used thresholds (i.e., small: 0.2; medium: 0.5; large: 0.8). Data are presented as mean ± standard deviation (*SD*), and for all analyses statistical significance was accepted as $p < 0.05$.

Results

Preliminary Manipulation Checks

There was no difference at baseline between the trials for daily stress ($t(18) = -0.38$, $p = 0.71$, $d = 0.09$) or fatigue ($t(18) = 2.02$, $p = 0.06$, $d = 0.32$). Therefore, it was not necessary to control for daily stress or fatigue in subsequent analyses. The manipulation of self-control did however affect mental exertion, as measured by the CR-10 scale, with participants reporting greater mental exertion on the self-control condition (5.42 ± 2.17) compared to the non-self-control condition (3.21 ± 1.51, $t(18) = 5.23$, $p \leq 0.01$, $d = 1.18$).

Repeated Sprint Task Performance

Descriptive statistics for MPO (W), PPO (W), average speed ($km \cdot h^{-1}$), and percentage fatigue (at sprint 1, sprint 2, sprint 3, sprint 4 and sprint 5) are shown in Table 3.1.

MPO (W). MPO (W) was not affected by the manipulation of self-control (main effect of self-control; $F(1,16) = 2.39$, $p = 0.14$). In addition, there was no difference in the pattern of change in MPO (W) over the repeated sprints between the trials (self-control*repeated sprint, $F(4,64) = 0.82$, $p = 0.47$).

PPO (W). There was a significant difference in participants' overall PPO (W) between each condition (main effect of self-control, $F(1,16) = 4.70$, $p = 0.05$). Upon further inspection, PPO (W) was significantly higher on the self-control condition (630 ± 112 W, 95% CI: 572 – 688 W) compared to non-self-control exertion condition (606 ± 120 W, 95% CI: 544 – 667 W, $t(16) = 2.17$, $p = 0.05$, $d = 0.21$). However, there was no difference in the pattern of change in PPO over the repeated sprints between the trials (self-control*repeated sprint, $F(4,64) = 0.81$, $p = 0.53$).

Average Speed (km·h^{-1}). Average speed (km·h^{-1}) was not affected by the manipulation of self-control (main effect of self-control; $F(1,16) = 0.23$, $p = 0.64$). In addition, there was no difference in the pattern of change in average speed (km·h^{-1}) over the repeated sprints between the trials (self-control*repeated sprint, $F(4,64) = 0.33$, $p = 0.86$).

Percentage Fatigue. Results indicated no statistically significant difference in participant's percentage fatigue ($t(16) = -0.27$, $p = 0.79$, $d = 0.05$). Specifically, there was no difference in percentage fatigue between the self-control exertion condition (12.21 ± 6.28%) and non-self-control exertion condition (12.53 ± 7.23%).

Table 3.1

Descriptive statistics for mean peak power output (W), peak power output (W), average speed (km·h^{-1}), and percentage fatigue (data are mean ± SD)

		Experimental Condition	
		Self-control exertion	**Non-self-control exertion**
MPO (W)	Sprint 1	578 ± 124	561 ± 126
	Sprint 2	523 ± 106	517 ± 109
	Sprint 3	494 ± 85	471 ± 85
	Sprint 4	457 ± 70	455 ± 83
	Sprint 5	458 ± 69	451 ± 75
PPO (W)	Sprint 1	678 ± 146	656 ± 157**
	Sprint 2	642 ± 130	626 ± 145
	Sprint 3	632 ± 120	590 ± 131
	Sprint 4	586 ± 103	573 ± 111
	Sprint 5	612 ± 110	582 ± 96
Average Speed (km·h^{-1})	Sprint 1	21.45 ± 2.72	21.56 ± 3.09
	Sprint 2	21.38 ± 2.82	21.18 ± 2.79
	Sprint 3	20.46 ± 2.24	20.43 ± 2.43
	Sprint 4	20.12 ± 2.28	19.78 ± 2.28
	Sprint 5	20.18 ± 1.94	19.78 ± 2.28
Percentage Fatigue (%)		12.21 ± 6.28	12.53 ± 7.23

** main effect of self-control $p \leq 0.05$

Subjective Scales and Physiological Measures

Descriptive statistics for perceptions of pain, motivation, RPE, heart rate (at sprint 1, sprint 2, sprint 3, sprint 4 and sprint 5), and blood lactate concentration (at baseline, immediately post repeated sprint task, 5 min post repeated sprint task) are shown in Table 3.2.

***Perceptions of Pain*.** Results indicated no statistically significant difference in initial perceptions of pain between experimental conditions ($t(18) = 0.64$, $p = 0.53$, $d = 0.10$). Overall perceptions of pain were not affected by the manipulation of self-control (main effect of self-control; $F(1,18) = 0.56$, $p = 0.46$). In addition, there was no difference in the pattern of change in perceptions of pain between the trials (self-control*repeated sprint, $F(5,90) = 1.85$, $p = 0.11$).

Motivation. Results indicated no statistically significant difference in initial motivation between experimental conditions ($t(18) = -1.79$, $p = 0.09$, $d = 0.24$). However, overall motivation was affected by the manipulation of self-control (main effect of self-control, $F(1,18) = 5.26$, $p = 0.03$), whereby motivation was lower in the self-control condition when compared to the non-self-control condition (self-control: 12.06 ± 3.66, 95% CI: 10.30 – 13.83; non-self-control: 12.96 ± 3.24, 95% CI: 11.41 – 14.53, $t(18) = -2.29$, $p = 0.03$, $d = 0.26$). However, there was no difference in the pattern of change in motivation between the trials (self-control*repeated sprint, $F(5,90) = 0.95$, $p = 0.45$).

***RPE*.** There was no effect of self-control on participants' RPE (main effect of self-control; $F(1,18) = 1.23$, $p = 0.28$). In addition, there was no difference in the pattern of change in RPE over the repeated sprints between the trials (self-control*repeated sprint, $F(5,90) = 1.38$, $p = 0.92$)

Heart Rate (beats per min). There was no effect of self-control on participants' heart rate (main effect of self-control; $F(1,18) = 2.12$, $p = 0.16$). In addition, there no difference in the pattern of change in heart rate over the repeated sprints between the trials (self-control*repeated sprint, $F(5,90) = 1.08$, $p = 0.38$).

Blood Lactate Concentration ($mmol{\cdot}L^{-1}$). There was no effect of self-control on participants' blood lactate concentration (main effect of self-control; $F(1,18) = 1.82$, $p = 0.19$). In addition, there no difference in the pattern of change in blood lactate concentration over the three measurements between the trials (self-control*time, $F(2,36) = 0.74$, $p = 0.49$).

Table 3.2

Descriptive statistics for initial pain, overall pain, initial motivation, overall motivation, ratings of perceived exertion, heart rate, blood lactate concentration (data are mean ± SD)

		Experimental Condition	
		Self-control exertion	**Non-self-control exertion**
Initial Pain		2.95 ± 1.81	2.74 ± 2.21
Overall Pain	Baseline	1.05 ± 0.23	1.16 ± 0.50
	Sprint 1	2.95 ± 1.81	2.74 ± 2.21
	Sprint 2	5.42 ± 4.05	5.16 ± 3.53
	Sprint 3	7.05 ± 4.81	7.53 ± 4.80
	Sprint 4	8.11 ± 4.99	8.95 ± 5.29
	Sprint 5	9.05 ± 5.73	9.79 ± 5.66
Initial Motivation		14.26 ± 3.93	15.16 ± 3.45
Overall Motivation	Baseline	15.05 ± 4.30	15.79 ± 3.89**
	Sprint 1	14.26 ± 3.93	15.16 ± 3.47
	Sprint 2	13.11 ± 3.93	14.05 ± 3.33
	Sprint 3	11.11 ± 4.41	12.53 ± 3.92
	Sprint 4	9.74 ± 4.39	10.89 ± 4.46
	Sprint 5	9.11 ± 5.30	9.37 ± 4.96
RPE	Baseline	1.47 ± 0.90	1.21 ± 0.54
	Sprint 1	8.42 ± 5.49	7.16 ± 5.13
	Sprint 2	11.58 ± 5.46	10.26 ± 4.85
	Sprint 3	13.63 ± 5.09	12.53 ± 4.49

	Sprint 4	15.16 ± 4.45	14.21 ± 4.28
	Sprint 5	16.68 ± 4.11	15.63 ± 3.96
Heart Rate (beats per min)	Baseline	108 ± 20	108 ± 14
	Sprint 1	136 ± 19	140 ± 13
	Sprint 2	157 ± 13	161 ± 9
	Sprint 3	168 ± 10	171 ± 7
	Sprint 4	171 ± 10	174 ± 8
	Sprint 5	173 ± 10	176 ± 6
Blood Lactate Concentration ($mmol \cdot L^{-1}$)	Baseline	1.17 ± 0.47	1.29 ± 0.39
	Immediately Post	11.01 ± 3.59	11.45 ± 3.45
	5 min Post	11.12 ± 4.05	11.72 ± 4.16

** main effect of self-control $p \leq 0.05$

Discussion

The present study examined the effects of exerting self-control on subsequent running repeated sprint task performance and whether perceptions of pain, motivation, and RPE are mechanisms that could explain any observed difference in performance. The main novel finding of the present study was that prior self-control exertion did not affect subsequent repeated sprint performance (MPO, PPO, and percentage fatigue). In addition, while participants' overall motivation was negatively impacted by the initial exertion of self-control, this did not result in any performance decrements. Moreover, participants' perception of pain and RPE were not affected by prior self-control exertion.

Contrary to our hypothesis, prior self-control exertion did not affect repeated sprint task performance, despite confirmation that the manipulation of self-control was successful (via the CR10 scale). Findings conflict with previous evidence that prior self-control exertion reduced subsequent physical task performance (Boat et al., 2020; Boat et al., 2021; Englert & Wolff, 2015; O'Brien et al., 2020; Wagstaff, 2014). One explanation for this finding could be due to the different performance domain being assessed in the present study, and more specifically the lack of decision making required during the repeated sprint task. Previous research has suggested that the exertion of self-control is a result of a conscious decision-making process to resist temptations and purse long-term goals (Knoch & Fehr, 2007). As participants were not required to continually exert effort over a prolonged period in the present study, there was no conscious decision regarding when to quit the repeated sprint task. In comparison, a physical task such a wall-sit task until volitional exhaustion requires an active decision to quit the task when the discomfort of the task outweighs the importance of achieving optimal performance (Boat et al., 2018; Kurzban et al., 2013). Furthermore, after each 6 s sprint, participants may have had an opportunity to replenish their self-control ready for the next upcoming sprint (Baumeister et al., 1998). Future research should examine the impact of self-control exertion on decision-making during a physical task, to understand when individuals choose to give into proximal temptations (i.e., reducing effort) instead of pursing distal goals (i.e., achieving optimal performance). Furthermore, it is possible that the active recovery periods between the sprints provided an opportunity for the restoration of self-control.

It must be acknowledged that participants' PPO (W) was higher in the self-control exertion condition when compared to the non-self-control condition. This finding is conflicting with previous research that suggests self-control exertion reduced PPO (W) (e.g., Englert, 2016, Zering, Brown, Graham & Bray, 2017). One possible explanation may be the negative impact self-control has been shown to have on pacing strategies (Boat et al., 2021). Previous research has demonstrated that individuals apply pacing strategies during repeated sprint exercise tasks to limit premature fatigue and ensure optimal task performance (e.g., Baron et al., 2009; Billaut, Bishop, Schaerz & Noakes, 2011). It could be suggested that prior self-control exertion resulted in participants failing to self-regulate pacing during the repeated sprint task. Whereby participants in the non-self-control exertion trial selected a pacing strategy that appeared to be more consistent over the course of the repeated sprint task (i.e., optimal self-regulation). In contrast the self-control exertion condition selected a pacing intensity that was too high to maintain throughout the repeated sprint task (i.e., suboptimal self-regulation). This theory is supported by there being no differences in MPO (W) between the trials in the present study. However, this explanation remains speculative at present and further research is required to explore the effects of self-control exertion on pacing strategies during endurance-based tasks.

Another key aspect of the present study is the investigation into the mechanisms that underpin the effects of self-control exertion on subsequent physical performance. A statistically significant main effect of prior self-control exertion on participants' overall motivation was demonstrated. However, there was no significant difference in participants' initial motivation or motivation between sprints at any time-point. In accordance, with the motivational aspect of *the shifting priorities model* (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017) and *opportunity-cost conceptualization* (Kurzban et al., 2013; Wolff & Martarelli, 2020) of self-control it is proposed that the initial exertion of self-control causes shifts in overall motivation, away from the distal goal (e.g., optimal physical performance) towards proximal temptation (reducing effort to alleviate discomfort). However, it must be noted that overall differences in motivation did not result in any performance decrements, therefore, caution must be taken when interpreting this result.

Building on from this, no statically significant differences were found for any other mechanisms assessed in the current study. Participants' initial and overall perceptions of pain were not affected by the initial exertion of self-control; thus, these findings do not align with the attentional aspects of *the shifting priorities model* of self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017). It could be suggested that due to the 24 s rest period between each sprint, participants were able to sufficiently alleviate any pain experienced during the previous sprint and restore self-control ready for the upcoming sprint (Masicampo, Martin & Anderson, 2014; Steinborn & Huestegge, 2016). Future research could explore the role of rest following the initial exertion of self-control and its potential to overcome the negative effects associated depletion effects in physical exercise.

In addition, no statistically significant difference was found for participants' initial or overall RPE. Findings align with previous research that suggests RPE is not an underpinning mechanism of self-control exertion, as typical self-control depletion tasks are not long enough to induce subjective feelings of effort (Pageaux, Marcora, & Lepers, 2013). Moreover, no statistically significant difference was found for participants' heart rate or blood lactate concentration between the conditions. This finding is aligned with previous research that has suggested prior cognitive exertion has no effect on cardiovascular responses during endurance performance following a cognitive manipulation (Boat, Taylor, Hulston, 2017; Boat et al., 2021; Marcora et al., 2009). Taken together these findings infer the perceptions of effort and physiological markers of effort do not appear to be suitable underpinning mechanism to explain performance differences following the exertion of self-control. Further research is necessary to investigate the relationship between effort following self-control exertion and physical performance to understand if individuals exert less effort following self-control exertion (Englert and Wolff, 2015, Wagstaff, 2014) or perceive that more effort is required following self-control exertion (Marcora et al., 2009).

Limitations and Future Directions

It is important to address some limitations of the current study. Although the treadmill allowed an objective measurement of performance measures, it is important to acknowledge that the repeated sprint task was artificial in nature and may not be generalizable to how repeated sprint performance is in a competitive environment (e.g., football match). However, the multitude of factors which could impact repeated sprint performance in such environments would be incredibly difficult to control. Regardless, future studies could employ methods such as using GPS technology to capture sprint performance measurements in real-time (Hoppe, Baumgart, Polglaze & Freiwald, 2018; Haugen & Buchheit, 2016).

In addition, in the current study we utilized a congruent and incongruent Stroop task for 4 min to manipulate self-control. However, previous research has suggested that engaging in longer durations of the initial self-control task (i.e., the incongruent Stroop used in this study) leads to greater reductions in performance on the subsequent physical task (Boat et al., 2020). Future research could employ an initial self-control task for a longer duration to explore if this leads to performance decrements in repeated sprint performance.

Finally, while the current study supports the motivational tenants of *the shifting priorities model* (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), it is important to note the current study relied on self-report measurements of underpinning mechanisms. Previous research has suggested that mechanisms may not be shown to influence physical performance when assessed by self-report (Stocker et al., 2020). Therefore, differences in participants' perceptions of pain may have been unidentified due to a lack of objective measurement. A movement towards more objective measures of pain (e.g., electromyography; Bray, Martin Ginis, Hicks & Woodgate; Huang et al., 2014) could be employed to further investigate pain as an underpinning mechanism of self-control during physical performance.

Conclusion

The findings of the present study imply that prior self-control exertion does not affect repeated running sprint performance. Furthermore, prior self-control exertion may cause shifts in motivational process during a repeated sprint task, however this did not result in reductions in performance. Finally, more objective measures of attentional mechanism such as perceptions of pain may be required to detect changes following the exertion of self-control.

Chapter Four

Boredom, motivation, and perceptions of pain: mechanisms to explain the effects of self-control exertion on subsequent physical performance

Abstract

Prior self-control exertion has been shown to have a detrimental effect on subsequent physical performance. However, some potential underpinning mechanisms of the effect have yet to be examined. The present study explored whether exerting self-control reduces subsequent physical performance; and also examines the role of boredom, motivation, perceptions of pain, and sustained attention as mechanisms to explain these performance effects. In a within-subjects order-balanced crossover design, 63 participants completed a self-control exertion task (incongruent Stroop) and non-self-control exertion task (congruent Stroop) for four minutes. Immediately after, participants completed a wall-sit task until volitional exhaustion. Task-specific boredom was measured following the Stroop task and following the wall-sit task. Participants' perceptions of pain and motivation were measured every 30 s during the wall sit task. Upon completion of the wall-sit, participants completed a test of sustained attention. Following the self-control exertion task, participant's wall-sit performance time was reduced (136±62 s), compared to when they completed the non-self-control exertion task (144±57 s, $p = 0.05$, $d = 0.14$). Participant's task related boredom was significantly higher during the non-self-control exertion task (4.30±1.23), compared to the self-control exertion task (3.82±1.22) ($p < 0.001$, $d = 0.39$); but boredom was not different during the wall-sit task (p = 0.79). Prior self-control exertion also led to increased overall perceptions of pain ($p = 0.02$) and reduced overall ($p = 0.01$) and initial ($p = 0.02$) motivation during the wall-sit task. However, no differences in initial perceptions of pain ($p = 0.16$) or sustained attention (response time, $p = 0.99$; response accuracy, $p = 0.78$) were observed. Additional within-subjects mediation analysis revealed that differences in wall-sit performance time could not be explained by differences in task related boredom during the Stroop task, overall perceptions of pain, or overall and initial motivation (all $p > 0.05$). The prior exertion of self-control resulted in a decrement in subsequent physical performance. Furthermore, individuals' perceptions of task related boredom were higher during the non-self-control exertion (congruent Stroop) task, whilst overall perceptions of pain were higher, and initial and overall motivation were lower, following the self-control exertion (incongruent Stroop) task. However, mediation analysis revealed that these mechanisms did not explain the difference in wall sit performance time between the conditions.

Key words: self-control; boredom; pain; motivation; mechanisms; cognitive exertion

Introduction

Self-control is the effortful inhibition of one's behavioral, emotional, and attentional impulses to achieve desired, long-term goals (Vohs & Baumeister, 2004). It has been categorized as a specific form of broader self-regulation processes in which an individual exerts deliberate and conscious effort to control behavior (Baumeister, Vohs, & Tice, 2007). The application of self-control is beneficial for a magnitude of adaptive behaviors, including higher academic achievement, effective diet management, and enhanced interpersonal relationships (de Ridder, Lensvelt-Mulders, Finkenauer, Roy, & Baumeister, 2012). Self-control is also imperative for sport and exercise (Englert & Taylor, 2021). For instance, athletes require high levels of self-control to remain persistent during endurance-based tasks to ensure optimal performance (e.g., cycling; Wagstaff, 2014) and adhere to exercise programs over a sustained period (e.g., exercise training plans; Martin Ginis, & Bray, 2010).

The capacity to use self-control can differ between individuals (i.e., trait self-control; Tangney, Baumeister, & Boone, 2004), as well as across situations within the same individual (i.e., state self-control; Gailliot, Gitter, Baker, & Baumeister, 2012). Regarding state self-control, a substantial evidence base has corroborated that the prior exertion of self-control on one task impairs performance on a subsequent, seemingly unrelated task also requiring self-control (Baumeister, Vohs, & Tice, 2007; Brown et al., 2020; Cunningham & Baumeister, 2016; Hagger et al., 2010). This notion is frequently tested using the sequential task-paradigm (Arber et al., 2017) in which participants engage in two tasks (Lee, Chatzisarantis, & Hagger, 2016). The primary tasks employed in the experimental (self-control exertion) condition are high self-control tasks that demand mental effort (e.g., incongruent Stroop task), whilst in the control (non-self-control exertion) condition participants complete a primary task that does not require self-control. Previous research has demonstrated that engaging in a primary task that requires high self-control has a negative effect on subsequent physical task performance (Brown et al., 2020).

The capacity for prior self-control exertion to result in performance decrements has been demonstrated in a multitude of physical tasks including cycling endurance tasks (Boat, Taylor, & Hulston, 2017; Boat, Williamson, Read, Jeong, & Cooper, 2021; Wagstaff, 2014), handgrip tasks (Graham, Li, Bray, & Cairney, 2018), wall-sit tasks (Boat, Atkins, Davenport, & Cooper, 2018; Boat et al., 2020), sit-up tasks (Dorris, Power, & Kenefick, 2012), and skill-based tasks (Boat, Sunderland, & Cooper, 2021; Englert, Bertrams, Furley, & Oudejans, 2015; McEwan, Ginis, & Bray, 2013). Although some research has failed to observe this effect (Hagger et al., 2016; Stocker, Seiler, Schmid, & Englert, 2020) leading to a degree of ambiguity in the evidence base (Carter et al., 2015; Holgada, Sanabria, Perales, & Vadillo, 2020; Wolff, Baumann & Englert 2018), recent meta-analytical findings have demonstrated compelling evidence that the prior exertion of self-control has a negative effect on subsequent task performance (Brown et al., 2020; Chapter Two; Giboin & Wolff, 2019).

This research area has recently progressed to explore the underpinning mechanisms explaining the negative impact of self-control exertion on subsequent physical performance. At present, increased perceptions of pain (particularly during the early stages of physical tasks) appear to be the most plausible mechanism explaining why physical performance decreases following prior self-control exertion (Chapter Two). However, recent literature has suggested that mechanisms such as perceptions of boredom, motivation, and sustained attention require further investigation (e.g., Boat et al., 2021; Chapter Two; Wolff, Bieleke, Stähler, & Schüler, 2020; Wolff & Martarelli, 2020). Specifically with regards to boredom, according to the Meaning and Attention Components (MAC) model, boredom develops when individuals perceive they are unable to effectively engage attention in a task and/or when the current activity is perceived as low in meaning or too difficult to complete (Westgate & Wilson, 2018). At this realization, individuals may become bored. Once feelings of boredom have increased, individuals may choose to weigh up the costs (e.g., pain) and benefits (e.g., optimal performance) of the physical task and begin to seek behavioral alternatives (e.g., quitting a wall-sit task) (Bieleke, Barton, & Wolff, 2021; Kurzban et al., 2013; Wolff & Martarelli, 2020). Controlling for boredom has been suggested as key to observing the depletion effect in previous self-control research (Mangin, Andréa, Benraissa, Pageaux, & Audiffrena, 2021). In addition, it has been proposed that the initial cognitive task within the sequential task paradigm may increase feelings of boredom, through understimulation (non-self-control exertion tasks) or overstimulation (self-control exertion tasks) (Wolff & Martarelli, 2020). However, to our knowledge, the role of boredom is yet to be empirically tested as an underpinning mechanism of self-control failure during a physical task.

Furthermore, with regards to motivation and perceptions of pain, a key theory that has been proposed to explain self-control failures is *the shifting priorities model* (Inzlicht, Schmeichel, & Macrae, 2014; Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017); which suggests that prior self-control exertion triggers a shift in attention and motivation, that in-turn causes reductions in physical performance on subsequent tasks (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017). Reduced motivation and increased perceptions of pain may lead to shifts in foci, towards the proximal temptation (e.g., alleviating pain) and seeking alternative behaviors (e.g., quitting a wall-sit task). Assumptions of this model are also accordant with the *opportunity-costs conceptualization* of self-control, whereby individuals deliberate the benefits of pursuing a specific task against its costs (Kurzban et al., 2013; Wolff & Martarelli, 2020). Specifically, research has demonstrated significant effects of prior self-control exertion on initial perceptions of pain and motivation (Boat et al., 2020, Boat et al., 2021). Thus, further investigation of motivation and perceptions of pain, particularly within the initial stages of a physical task, is warranted to enhance understanding of how self-control exertion influences subsequent sport and exercise performance.

Finally, considering the proposition that attention is a key mechanism underpinning self-control failure (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017); there is limited research examining the effects of self-control exertion on sustained attention during subsequent physical performance tasks. Previous research has demonstrated that high levels of self-control are required to persistently sustain attention whilst engaging in a sport shooting task, over a prolonged period (e.g., Englert Dziuba, Giboin, Wolff, 2021; Englert, Dziuba, Wolff, & Giboin, 2021). However, to date, only one study has demonstrated a detrimental effect of prior self-control exertion on sustained attention during a sporting performance task (field hockey skills task); whereby, participants made more errors on a cognitive task designed to assess attention (Rapid Visual Information Processing Test; RVIPT) following self-control exertion, compared to a control condition (Boat et al., 2021).

Therefore, the aims of the current study were to determine whether the prior exertion of self-control reduces subsequent physical performance; and whether boredom, motivation, perceptions of pain, and sustained attention are mechanisms that explain the performance effects. Considering the extensive self-control literature (e.g., Boat et al., 2020; Boat et al., 2021; Wolff & Martarelli, 2020), it was hypothesized that prior self-control exertion on a cognitively demanding task (i.e., incongruent Stroop task) would result in reduced physical performance (hypothesis 1), as well as increased perceptions of pain, reduced motivation, and impaired sustained attention (hypothesis 2) during the wall-sit task, compared to a control condition (i.e., congruent Stroop task). Finally, given the novelty of examining boredom as a potential mechanism, this aspect of the study was exploratory.

Methods

Participants

The sample consisted of 63 participants (31 male, 32 female) aged 18-28 years old (*M* age = 21.3 years, *SD* = 2.3 years). Participants all reported that they were recreationally active, exercising on average four days (*SD* = 1 day) per week. All participants were healthy, as determined by a University approved general health questionnaire (see Appendix 3). A power calculation (G*Power version 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) with power = 0.95 and $\alpha = 0.05$, specified a minimum sample size of $N = 54$ would be satisfactory to detect a medium effect size ($d = 0.5$), which is representative of previous self-control studies (Boat et al., 2020; Brown et al., 2020; Giboin & Wolff, 2019).

Procedures

Following approval from a University ethics committee, each participant signed an informed consent form (see Appendix 10) after the study was explained in full and it was described that participation was anonymous and voluntary (see Appendix 11 for participant information sheet). Furthermore, participants were asked to refrain from strenuous exercise and avoid alcohol and caffeine intake 48 hours before the start of each laboratory visit. Participants took part in two experimental sessions in total (separated by at least 48 hours).

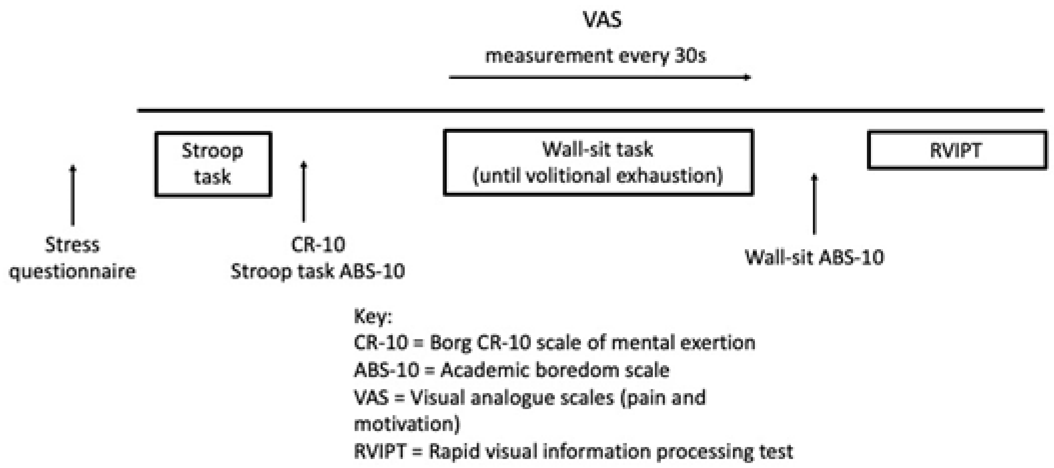
Experimental Protocol

The experimental protocol can be found in Figure 4.1. On arrival to the first experimental session at the laboratory, participants were required to complete a daily stress questionnaire (see measures section), due to the potential for stress to influence the effect of self-control exertion on subsequent physical performance (Englert & Rummel, 2016; Tangney et al., 2004).

Participants were then familiarized with the wall-sit procedure. Individuals were instructed to lean with their back against a wall, hips and knees bent at 90-degrees, feet shoulder width apart, with their hands resting on their thighs. The wall-sit task involves self-control as it requires participants to invest sustained effort to hold the wall-sit position for as long as possible, while overcoming the temptation to quit the wall-sit to alleviate the increasing feelings of physical distress that develop as the wall-sit task progresses (Boat et al., 2018; Boat et al., 2020). The physical task instructions were scripted so that they remained the same for each participant. Individuals practiced the wall-sit task to ensure that they understood what was required, but they were not asked to persist at the task. This procedure has been used successfully in similar self-control research (e.g., Boat et al., 2018; Boat et al., 2020).

Figure 4.1

Experimental protocol demonstrating the timing of each measurement during the experimental trials.



Participants were then required to complete a self-control exertion task (incongruent Stroop task) or a non-self-control exertion task (congruent Stroop task) for 4 min, in a randomized, order-balanced, cross-over design. A modified Stroop task (Stroop, 1935) was used as the experimental manipulation in this study. This task is a well-established self-control task and has been successfully applied in previous self-control research (e.g., Boat et al., 2020; Englert & Wolff, 2015; McEwan et al., 2013). Furthermore, this duration of the Stroop task was utilized as previous research has demonstrated negative effects on subsequent physical performance following a 4 min incongruent Stroop task (e.g., Boat & Taylor, 2017; Boat et al., 2020).

In the Stroop task, a word (always a color) was displayed in the center of a computer screen, and participants were required to select the colored response pad button that matched the color of the print ink. In the congruent version of the Stroop task (non-self-control exertion), the word and color were matched (e.g., the word "black" was printed in black ink). In the incongruent version of the Stroop task (self-control exertion), the printed text and print ink color were mismatched. For example, if the word “black” was printed in pink ink, the correct response would be pink. The incongruent version of the Stroop task has frequently been shown to be a cognitively challenging task that requires self-control, whereby participants are required to volitionally overrule their initial impulse to name the ink color, as opposed to the word (e.g., Boat et al., 2020; Englert & Wolff, 2015; McEwan et al., 2013). The Stroop task was completed on a laptop computer, with a head-to-monitor distance of 80–100 cm, via custom-made software (SuperLab 6.0) with words serially presented on the screen. Participants were instructed to respond as accurately and quickly as possible. Stimuli remained on the screen until participants responded. There was an inter-stimulus interval of 1 s. Prior to the actual test, participants completed a practice session lasting 30 s to familiarize themselves with the task and response pad. Immediately following the Stroop task, participants completed two subsequent questionnaires. As a manipulation check, participant’s perceived mental effort during the cognitive task was assessed (CR-10 Scale; Borg 1998). In addition, participants were asked to complete the Academic Boredom Scale (ABS-10; Acee et al., 2010) to rate their perception of boredom during the Stroop task (see measures section).

Immediately following the completion of the questionnaires, participants performed the wall-sit. Participants were instructed to hold the position for as long as possible, until volitional exhaustion. Throughout the wall-sit task, participants’ perceptions of pain and motivation were recorded every 30 s (see measures section). Immediately after the wall-sit, participants were required to complete the ABS-10 scale (Acee et al., 2010), this time focusing on rating their perception of boredom during the wall-sit task (see measures section). Finally, participants were required to complete the RVIPT, to assess their sustained attention (see measures section). The RVIPT is a well-established cognitive function test that has been frequently demonstrated as an appropriate measure of sustained attention (e.g., Chandler, McGowan, Ferguson & Pontifex, 2020; Sun, Cooper, & Tse, 2020).

Measures

Daily Stress. Daily stress was measured using the seven stem questions from the Daily Inventory of Stressful Events Questionnaire (Almeida, Wethington, & Kessler, 2002). Participants were asked to report whether any of a number of stressful events had occurred today by circling either “yes” or “no” (e.g., “An argument or disagreement with someone”). The items have demonstrated acceptable internal consistency and predictive validity in previous research (Almeida et al., 2002) (see Appendix 6).

Mental Exertion. Borg's single-item CR-10 scale was utilized to rate participants' mental exertion during the Stroop task (Borg, 1998; 0 = extremely weak; 10 = absolute maximum), with higher scores representing more perceived mental exertion. This single item measure has frequently been used in previous research (e.g., Boat et al., 2020; McEwan et al., 2013) (see Appendix 8).

Perceptions of Boredom. Participants' boredom was measured using the ten-item Academic Boredom Scale (ABS-10; Acee et al., 2010). As per previous research (Sharp, Sharp, & Young, 2020; Vodanovich & Watt, 2016), items were answered on a nine-point Likert scale (1 = not at all; 9 = extremely). Participants were required to select to what extent they agreed with each item (e.g., "to what extent did you find the activity dull?"). Participants completed this measure twice, immediately after completing the Stroop task and immediately after the wall-sit task. These items have shown suitable levels of internal consistency ranging from $\alpha = 0.78$ to 0.91 (Acee et al., 2010; Vodanovich & Watt, 2016) (see Appendix 12).

Perceptions of Pain and Motivation. Participants' perceptions of pain and motivation to continue with the wall-sit task were measured using a Visual Analog Scale (VAS), adapted from the short-form McGill pain questionnaire (SF-MPQ; Melzack, 1987). On a 10 cm line, participants were instructed to make a mark to indicate their current perceptions of pain and motivation. Perceptions of pain were marked on a continuum where one end indicated no pain, and the other end represented the worst pain. Similarly, on the motivation VAS, one end indicated zero motivation to continue with the wall-sit task and the other end indicated full motivation to continue with the wall-sit task. Participants were required to complete the VAS at 30 s intervals for the duration of the wall-sit task. The VAS has demonstrated acceptable reliability and predictive validity in previous research (Wright, Asmunds, & McCreary, 2001) (see Appendix 13).

Task Performance. Physical performance was measured using participants' wall-sit task time to exhaustion (in seconds). The wall-sit was concluded when participant's knees extended above, or flexed below, the required 90-degree angle they were asked to maintain during the wall-sit, or at the point of volitional exhaustion.

Sustained Attention. The Rapid Visual Information Processing Test (RVIPT) was used to assess sustained attention. Participants were presented with a sequence of single digits (2–9) placed in the center of the computer screen at a rate of 100 digits$\cdot$min^{-1} and were instructed to respond using the 'space' button on the computer keyboard as soon as they detected any target sequence including three consecutive odd or even numbers (e.g., 2-6-4, 5-

3-9). Correct sequences could be identified during the time the final digit was displayed on the screen and for the subsequent 1500 ms. Participants were provided with an opportunity to practice the test. Mean reaction time to correctly respond to target sequences and the proportion of correct responses during the 5 min testing block were recorded to provide an objective measure of sustained attention. The RVIPT has successfully been used as a measure of sustained attention in previous research (e.g., Chandler et al., 2020; Sun et al., 2020).

Statistical Analysis

Data were analyzed using SPSS (version 26; SPSS Inc., Chicago, IL., USA). To check for baseline differences between the conditions, wall-sit performance time, stress, and mental exertion were analyzed using paired samples *t*-tests. Separate paired sampled *t*-tests were also conducted to assess differences in boredom (following both the Stroop task and wall-sit task) and sustained attention between the conditions. For all analyses, statistical significance was accepted as $p \leq 0.05$. Effect sizes for paired samples *t*-tests were calculated using Cohen's *d* and interpreted in accordance with commonly used thresholds (i.e., small: 0.2; medium: 0.5; large: 0.8).

Due to the different number of data points for perceptions of pain and motivation (measured every 30 s throughout the wall-sit task), multi-level modeling was used to analyze these data using R (version 4.0.5; www.r-project.org). Specifically, linear mixed effect models (using the *lme* function) were employed, yielding *t* statistics. Perceptions of pain and motivation were both analyzed using a repeated measures condition * time approach, with a random effect (intercept) for each participant. Subsequently, based upon suggestions within the literature that motivation and perceptions of pain are particularly affected during the early stages of a physical performance task (Boat et al., 2020), pairwise comparisons for initial motivation and perceptions of pain (measured at 30 s) between the conditions were also performed using linear mixed effect models. Model outcomes are reported as parameter estimates (*b*) with 95% confidence intervals.

Following the preliminary analysis, variables that demonstrated a statistically significant difference between the self-control exertion and non-self-control exertion conditions were tested for mediation. Within-subject mediation analysis (Judd, Kenny & McClelland, 2001), using the MEMORE macro (Montoya & Hayes, 2017), was conducted to test whether the mechanisms mediated the observed difference in wall-sit performance time. MEMORE has been specifically developed for cases in which the experimental manipulation varies within participants, as per this study. This analysis provides estimates of total, direct, and indirect effects, and produces confidence intervals for inference about the indirect effect using bootstrapping techniques. Five thousand bootstrapping samples were used in the current study. This approach has previously been suggested to yield adequate power for detecting mediation using within-subjects designs and greater power than traditional inferential statistics (Montoya, 2022; Muller, LaVange, Ramey, & Ramey, 1992).

Results

Preliminary Manipulation Checks

Table 4.1 displays descriptive statistics for each variable across each experimental condition. The successful manipulation of self-control was demonstrated as participants reported higher levels of mental exertion following the incongruent Stroop task (M = 5.17, SD = 2.14) compared to the congruent Stroop task (M = 3.63, SD = 1.42, $t(62)$ = 6.04, p < 0.001, d = 0.86). Participants did not differ in levels of daily stress ($t(62)$ = -0.219, p = 0.83, d = 0.03), therefore, it was not necessary to control for daily stress in subsequent analyses.

Wall-sit Performance Time

Results indicated a statistically significant difference in wall-sit performance time ($t(62)$ = -1.99, p = 0.05, d = 0.14). Specifically, wall-sit time to volitional exhaustion was reduced in the self-control exertion condition (M = 136, SD = 62 s) compared to the non-self-control exertion condition (M = 144, SD = 57 s).

Perceptions of Boredom

Results indicated statistically significant differences in perceptions of boredom during the Stroop task ($t(62)$ = 3.74, p < 0.001, d = 0.39). Specifically, participants perception of boredom was higher after completing the congruent Stroop task (M = 4.30, SD = 1.23), when compared to the incongruent Stroop task (M = 3.82, SD = 1.22).

Furthermore, results indicated no statistically significant difference in perceptions of boredom during the wall-sit task between experimental conditions ($t(62)$ = -0.27, p = 0.79, d = 0.02).

Perceptions of Pain

Overall, perceptions of pain were greater in the self-control exertion condition, compared to the non-self-control condition (b = 0.45, 95% CI = 0.08, 0.82; main effect of condition, $t(498)$ = 2.40, p = 0.02). Perceptions of pain also increased over time (b = 1.02, 95% CI = 0.84, 1.20; main effect of time, $t(498)$ = 11.74, p < 0.001). However, the pattern of change in perceptions of pain was not different over time between the self-control exertion and non-self-control exertion condition (condition * time interaction, p = 0.22).

When examining initial perceptions of pain (at 30 s), there was no difference between the self-control exertion and non-self-control exertion conditions (p = 0.16).

Motivation

Overall, motivation was lower in the self-control exertion condition, compared to the non-self-control exertion condition (b = -0.68, 95% CI = -1.17, -0.19; main effect of condition, t(498) = 2.7, p = 0.01). Motivation also decreased over time during the wall-sit task (b = -0.59, 95% CI = -0.83, -0.35; main effect of time, t(498) = -5.02, p < 0.001). Furthermore, there was a significant condition * time interaction for motivation, whereby the reduction in motivation across time was greater in the self-control exertion condition (b = -0.17, 95% CI = -0.31, -0.03; condition * time interaction, t(498) = -2.29, p = 0.02), compared to the non-self-control exertion condition.

Upon further inspection, initial motivation (at 30 s) was lower in the self-control exertion condition, compared to the non-self-control exertion condition (b = -0.45, 95% CI = -0.82, -0.08; t(62) = -2.38, p = 0.02).

Sustained Attention

No significant differences were found in mean response time on the RVIPT (t(62) = -0.002, p = 0.99, d = 0.0) or response accuracy (t(62) = -0.276, p = 0.78, d = 0.0), between the experimental conditions.

Table 4.1

Descriptive statistics for mental exertion, daily stress, boredom, and sustained attention variables (data are mean ± SD).

	Experimental Condition			
	Self-control exertion		Non-self-control exertion	
Variable	*M*	*SD*	*M*	*SD*
Mental Exertion	5.17	2.14	3.63	1.42*
Daily Stress	0.71	1.11	0.68	0.93
Wall-sit Performance Time (s)	136	62	144	57**
Boredom				
- ABS-10 Stroop task	3.82	1.22	4.30	1.23*
- ABS-10 Wall-sit	3.59	1.17	3.56	1.25
Sustained Attention				
- Response Time (ms)	510	66	510	65
- Response Accuracy (%)	47.9	18.9	47.5	15.9

* $p < 0.001$, ** $p < 0.05$

Mediation Analysis

Within-subject mediation analysis was conducted to test whether perceptions of task related boredom during the Stroop task, overall perceptions of pain, and motivation (both overall and initial) mediated the observed difference in wall-sit performance time (given that these variables displayed a statistically significant difference between the conditions). Results for perceptions of task related boredom during the Stroop task established a significant total effect of experimental condition on wall-sit performance time (b = -8.56, 95% CI = -17.31, 0.01; p = 0.05). Moreover, non-significant direct (b = -6.64, 95% CI = -16.18, 2.91; p = 0.17) and indirect (b = -2.02, 95% CI = -6.77, 1.39; p = 0.34) effects were observed. Therefore, perceptions of task related boredom during the Stroop task did not explain differences in wall-sit performance time between experimental conditions.

The mediation analysis was then repeated with participants' overall perceptions of pain. Results for overall pain demonstrated a significant total effect of experimental condition on wall-sit performance time (b = -8.65, 95% CI = -17.31, 0.01; p = 0.05). In addition, significant direct effects were found (*b* = -8.88, 95% CI = -17.44, -0.32; *p* = 0.04). However, non-significant indirect effects were observed (*b* = 0.22, 95% CI = -0.85, 3.14; *p* = 0.72). Therefore, overall perceptions of pain during the wall-sit task did not explain differences in performance between experimental conditions.

Finally, the mediation analysis was repeated with participants' overall and initial (i.e., within the first 30 s) motivation. Results for overall motivation demonstrated a significant total effect of experimental condition on wall-sit performance time (*b* = -8.65, 95% CI = -17.31, 0.01; *p* = 0.05). In addition, significant direct effects were found (*b* = -8.69, 95% CI = -17.28, -0.09; *p* = 0.05). However, non-significant indirect effects were observed (*b* = 0.03, 95% CI = -1.81, 1.40; *p* = 0.94). Therefore, overall motivation during the wall-sit task did not explain differences in performance between experimental conditions.

Similarly, results for initial motivation indicated a significant total effect of experimental condition on wall-sit performance time (*b* = -8.65, 95% CI = -17.31, 0.01; *p* = 0.05). In addition, non-significant direct (*b* = -4.96, 95% CI = -13.37, 3.46; *p* = 0.24) and indirect (*b* = -3.69, 95% CI = -7.43, -0.62; *p* = 0.06) effects were observed. Therefore, initial motivation during the wall-sit task did not explain differences in performance between experimental conditions.

Discussion

The present study examined the effects of exerting self-control on subsequent wall-sit task performance, and whether boredom, motivation, perceptions of pain, and sustained attention are mechanisms that could explain any observed differences in performance. Wall-sit performance time was significantly lower following self-control exertion, when compared to the non-self-control exertion condition. In addition, novel findings of the present study demonstrated that perceptions of task-related boredom during the Stroop task were higher when completing the non-self-control exertion condition, compared to the self-control exertion condition. Furthermore, prior self-control exertion resulted in increased overall perceptions of pain, and reduced overall and initial (i.e., within the first 30 s) motivation during the wall-sit task. However, there were no differences in initial perceptions of pain, sustained attention, or task-related boredom measured during the wall-sit task. Subsequently, mediation analysis revealed that perceptions of task-related boredom during the Stroop task, overall perceptions of pain, and overall and initial motivation, did not explain the reductions in physical performance following self-control exertion.

A key finding of the present study is that participants quit the wall-sit task quicker following the self-control exertion condition (i.e., incongruent Stroop task), compared to when they completed the non-self-control condition (i.e., congruent Stroop task). Whilst the direction of the effect (i.e., performance decrements following self-control exertion) is in line with previous research (Brown et al., 2020; Englert, 2019; Giboin & Wolff, 2019), the present study demonstrated a smaller effect size (d = -0.14) than previously suggested in recent meta-analytical work (e.g., g = -0.55, Chapter Two). Whilst the power calculation in the present study was performed based on a medium effect size (i.e., in line with recent meta-analyses; e.g., Chapter Two), a small effect size was detected yet this still reached statistical significance.

The investigation into perceptions of boredom as a potential mechanism underpinning the effects of prior self-control exertion on subsequent physical performance produced some key novel findings. It was demonstrated that perceptions of boredom were higher when participants completed the non-self-control task (congruent Stroop task) compared to the self-control exertion task (incongruent Stroop task). Findings are aligned with suggestions that experimental control tasks frequently used within the self-control literature (e.g., congruent Stroop task) may increase boredom due to under-stimulation (Wolff, Bieleke, Martarelli, & Danckert, 2021; Wolff & Martarelli, 2020). The findings are also in accordance with the assumptions of the MAC model, whereby boredom develops when individuals perceive that they are unable to effectively engage attention in a task and/or when the activity is perceived as low in meaning or too difficult to complete (Westgate & Wilson, 2018; Wolff & Martarelli, 2020). Previous literature has suggested that higher levels of boredom during the non-self-control task may account for some of the inconsistences within the literature (Wolff & Martarelli, 2020; Wolf et al., 2021).

Specifically, boredom during the non-self-control task has been suggested to confound the effects of self-control exertion through placing an unwanted demand on self-control as individuals are tempted to seek behavioral alternatives when boredom is increased (Wolff & Martarelli, 2020). Consequently, it could be implied that individuals demonstrate higher levels of performance on a subsequent task as a means of alleviating boredom. Despite this suggestion, to our knowledge, the present study is the first to empirically investigate the potential for boredom to explain differences in physical performance following the exertion of self-control. Although there was a difference in task-related boredom on the Stroop task between the self-control exertion and non-self-control exertion conditions, additional within-subjects mediation analysis did not establish Stroop task boredom as a mechanism to explain the difference in wall-sit task performance. However, it is noteworthy that a longer initial self-control task may result in increased levels of boredom, triggering increased self-control demands (Bieleke, Barton, & Wolff, 2021). Subsequently, this may result in higher levels of cognitive fatigue and cause decrements to performance (Mangin et al., 2021). Therefore, further empirical research is essential to understand the impact of self-control exertion on boredom levels, and subsequent physical performance.

In addition, the present study demonstrated no significant difference in boredom between the self-control exertion and non-self-control exertion trials during the wall-sit task. Findings may be a result of the nature of the wall-sit task. This effortful and increasingly difficult physical task requires individuals to overcome feelings of discomfort to persist at the task. The high physical demands of the task may have overshadowed any feelings of boredom resulting in no differences being observed. Overcoming feelings of boredom may be more important during less effortful tasks that still require self-control (e.g., practicing basketball free throw technique). Prior self-control exertion may result in differences in boredom as individuals begin to weigh up the benefits and costs of continuing as the monotony of the task increases (Kurzban et al., 2013; Wolff et al., 2021).

Another key finding of the present study was that the exertion of self-control led to reduced overall and initial (i.e., within the first 30 s) motivation during the wall-sit task. These findings support *the shifting priorities* and *opportunity-cost* models of self-control (Inzlicht et al., 2014; Inzlitch & Schmeichel, 2016; Kurzban et al., 2013), whereby increased states of distress within the initial stages of the wall-sit task incites participants to consciously focus on the presence of task goal conflict (e.g., quitting or reducing effort to reduce physical distress verses persisting on the wall-sit) (Baumeister & Bargh, 2014). Subsequently, motivational foci are shifted towards an increased focus on the proximal tempting goals (e.g., reducing effort or quitting), relative to the distal goal (e.g., persisting on the wall-sit task to optimize performance). Although differences in overall and initial motivation were observed between the self-control exertion and non-self-control exertion conditions, additional within-subjects mediation analysis did not establish motivation as a mechanism to explain the differences in wall-sit performance time. While measures of intrinsic and task motivation have previously been suggested to explain the effects of prior self-control exertion on physical performance (e.g., Boat et al., 2018; Boat et al., 2021), more nuanced aspects of motivation, such as goal commitment and exercise intentions could be more suitable mechanisms to explain differences in performance (Brown & Bray, 2019). Further research employing mediation analysis is required on such variables, to establish which mechanisms explain the effects of self-control on physical performance.

In addition, prior self-control exertion was found to increase participants overall perceptions of pain during the wall-sit task. Findings are aligned with previous research that has found an increase in perceptions of pain following self-control exertion (Boat & Taylor, 2017; Boat et al., 2020). In addition, findings support the attentional shifts suggested by *the shifting priorities* and *opportunity-cost* models of self-control (Inzlicht et al., 2014; Inzlitch & Schmeichel, 2016; Kurzban et al., 2013). Although differences in overall perceptions of pain were observed between the self-control exertion and non-self-control exertion conditions, additional within-subjects mediation analysis did not establish overall perceptions of pain as a mechanism to explain the differences in wall-sit performance time. These findings highlight the need for more objective measurements of pain, to further examine pain as an underpinning mechanism that may explain why prior self-control exertion effects subsequent physical performance. For example, previous research has demonstrated that electromyography (EMG) activity of the facial muscles can successfully reflect the perception of effort and discomfort during high-intensity exercise (Huang et al., 2014). Therefore, this technique could be used to objectively measure perceptions of effort and pain in conjunction with self-report measures of perceptions of pain. The inclusion of such objective measures would provide valuable insight into this proposed underpinning mechanism (Huang, Chou, Chen, & Chiou, 2014).

Prior self-control exertion was found to have no effect on participant's sustained attention, as assessed by the RVIPT. Whilst previous research has suggested prior self-control exertion to negatively affect sustained attention (Boat et al., 2021), it is possible that the non-statistically significant results demonstrated for sustained attention were due to the length of time between participants completing the initial self-control exertion task and the RVIPT. Previous research suggests that there may be a washout period in which the detrimental effects of self-control exertion are no longer present, and an individual's self-control is replenished (Tyler & Burns, 2008). However, in the present study it was not possible for participants to complete the RVIPT until the wall-sit task and subsequent boredom measurement was completed. Further research is necessary to investigate the time course of these effects, which will have implications for the timing of measurements in future self-control studies.

Limitations and Future Research Directions

It is important to address some potential limitations of the present study. Whilst the wall-sit task does require muscular endurance, the task is not sport specific. There has been recent endeavor to investigate the effects of self-control exertion on “real life” sporting performance tasks that require self-control (e.g., hockey skill tasks; Boat et al., 2021). Future research should aim to employ ecologically valid performance tasks. In addition, while the Stroop task has previously been used successfully to manipulate self-control exertion in similar studies (e.g., Boat et al., 2020; Brown & Bray, 2019; Graham et al., 2018), it is noteworthy to acknowledge that the Stroop task is not sport specific and is relatively artificial in nature (Englert, 2016). Future studies could aim to employ sport specific measures to deplete self-control to make outcomes more applicable to sport practitioners.

Moreover, although our findings are consonant with *the shifting priorities* model of self-control from a motivational viewpoint (Milyavskaya & Inzlicht, 2017), more objective measures of motivation may provide valuable insight into this proposed underpinning mechanism. For example, electroencephalogram and fNIRS activity of the prefrontal cortex could be employed to investigate underlying motivational processes (Schmeichel, Crowell, & Harmon-Jones, 2016). As a result, such methods may allow for the objective investigation of shifts in motivational processes during a physical task, following prior self-control exertion.

Finally, whilst additional within-subjects mediation analysis could not establish that differences in wall-sit performance time were explained by changes in task related boredom during the Stroop task, overall perceptions of pain, or overall and initial motivation, it must be acknowledged that findings may be limited by the size of the total effect (d = 0.14). It is plausible that our mediational analysis may have yielded significant indirect effects if our experimental manipulation produced greater total effects on wall-sit performance. Caution should be taken when selecting the subsequent physical performance task as this has been shown to significantly impact performance results (Brown et al., 2020; Chapter Two). In addition, further mediational research is required to understand the relationship of the ‘causal chain’ between self-control exertion and potential mechanisms for the effect (Chapter Two).

Conclusion

The present study provides evidence that initial self-control exertion reduces performance on a subsequent physical task also requiring self-control, as evidenced by reduced wall-sit sit performance time. Furthermore, a key novel finding was that individuals’ perceptions of task related boredom were higher during the non-self-control exertion task (congruent Stroop), whilst overall perceptions of pain were higher, and initial and overall motivation were lower, following the self-control exertion task (incongruent Stroop). However, mediation analysis revealed that these mechanisms did not explain the difference in wall sit performance time between the conditions. Future research should further explore these mechanisms and temporal nature, to ultimately inform the design of interventions to attenuate the effects of prior self-control exertion on subsequent physical performance.

Chapter Five

Self-control exertion and goal priming: Effects on time-to-exhaustion cycling performance

Abstract

Prior self-control exertion has been shown to have a detrimental effect on subsequent physical performance. However, interventions to attenuate these negative effects on physical performance are limited. The current study had three primary objectives: a) to investigate whether prior self-control exertion reduced subsequent performance on a time-to-exhaustion cycling task (TTE), b) to investigate if goal priming attenuated the detrimental effects of self-control depletion on subsequent physical performance, c) to examine the potential for any observed performance decrements to be explained by changes in perceptions of pain and motivation. Fourteen recreationally active males (22.9±3.1 y) completed three TTE cycling tasks at 80% $\dot{V}O_2$ peak on an electromagnetically braked cycle ergometer (Lode Bike). Prior to each TTE, participants completed a self-control depletion task (incongruent Stroop task) or a non-self-control depletion task (congruent Stroop task) for 4 min. During the TTE, participants were asked to watch a video on the screen in front of them. During this video, participants were exposed to a goal priming sequence (intervention condition) or a random letter sequence (control condition). Participants completed the TTE cycling task on three separate occasions: self-control depletion/goal priming condition; self-control depletion/control condition; non-self-control depletion/control condition. The participants' TTE performance time, subjective measures (perceptions of pain, motivation, task importance, and RPE), and cycling cadence were recorded every 3 min during the TTE task. A one-way repeated measures ANOVA revealed that there was no significant difference in TTE task performance between the experimental conditions ($p = 0.28$). Furthermore, there were no significant changes in perceptions of pain ($p = 0.36$) or motivation ($p = 0.21$) throughout the TTE cycling task. However, a significant difference was demonstrated for participants' cycling cadence ($p = 0.01$). Post hoc t-tests revealed that participants cycled at a higher cadence in both the self-control depletion/goal priming intervention condition and the non-self-control depletion/control condition, when compared to the self-control depletion/control condition (both $p < 0.01$). The findings indicate that prior self-control exertion did not negatively affect subsequent TTE cycling performance. In addition, goal priming does not improve endurance performance or influence the effects of initial self-control exertion on subsequent physical task performance.

Key words: self-control; goal priming; intervention; mechanisms; cognitive exertion

Introduction

Self-control refers to a conscious, deliberate, and effortful process that any individual employs to alter their habitual states or responses, to aid the regulation of behavior in order to attain a desired end state or goal (Baumeister, Vohs & Tice, 2007; Graham & Brown, 2020). Self-control is not exerted until a temptation has the potential to direct behavior out of line with our broader goals (Graham & Brown, 2020). The capability to employ self-control can differ between individuals (i.e., trait self-control; Tangney, Baumeister & Boone, 2004), as well as across situations within the same individual (i.e., state self-control; Gailliot, Gitter, Baker & Baumeister, 2012). Demonstrating high levels of self-control has been associated with various beneficial behavioral outcomes such as improved well-being, enhanced academic achievement, and better interpersonal relationships (de Ridder, van der Weiden, Gillebaart, Benjamins & Fekke Ybema, 2020). Furthermore, self-control is essential for optimal athletic performance given that athletes are required to regulate their cognitive, emotional, and motor processes (Englert, 2016). For example, athletes who participate in endurance based physical tasks that require working at high intensities for prolonged periods of time are required to resist discomfort and the temptation to reduce effort, and instead invest sustained effort to produce optimal performance (Boat, Williamson, Read, Jeong, Cooper, 2021; Taylor, Boat & Murphy, 2018).

Regarding state self-control, an extensive body of research has demonstrated that following an initial task requiring self-control, an individual's ability to exert self-control on a seemingly unrelated subsequent task also requiring self-control is impaired (e.g., Boat et al., 2020; Boat et al., 2021; Bray, Oliver, Graham & Martin Ginis, 2013; Englert & Wolff, 2015; O'Brien, Parker, Moore & Fryer, 2020; Wagstaff, 2014). This phenomenon is regularly referred to as the depletion effect, and it is widely recognized that physical task performance is susceptible. While some research has failed to observe this effect (Hagger & Chatzisarantis, 2016; Stocker, Seiler, Schmid & Englert, 2020) leading to a degree of doubt in the evidence base (Carter et al., 2015; Wolff, Baumann & Englert 2018), recent meta-analytical evidence has found a small-to-medium ($g = -0.45$; Brown et al., 2020; $g = 0.55$; Chapter Two; $d = -0.506$; Giboin & Wolff, 2019) negative effect of prior self-control exertion on subsequent physical task performance.

To explain self-control failures, several theoretical models have been established. The more traditional model is the *strength model of self-control*, which suggests exerting self-control draws from a limited central resource (Baumeister et al., 2007). This central resource is susceptible to becoming depleted if used over time. This state is referred to as ‘ego depletion’ (Baumeister, Bratslavsky, Muraven & Tice, 1998). Once in this depleted state, an individual’s ability to apply additional self-control is reduced, resulting in performance decrements on subsequent acts of self-control (Hagger, Wood, Stiff & Chatzisarantis, 2010). Although the *strength model of self-control* perspective is supported by empirical and meta-analytical research (e.g., Dang, 2018; Hagger et al., 2010), recent replication studies and reviews have criticized the validity of the strength model (e.g., Kurzban, 2010; Carter, Kofler, Forster, & McCullough, 2015; Wolff, Baumann & Englert, 2018). In addition, research has demonstrated that performance decrements following initial self-control exertion are not evident when individuals were provided with monetary incentives (Brown & Bray, 2017), meditated (Friese, Messner & Schaffner, 2012), or offered choice (Moller et al., 2006). As a result, concerns regarding the identification of the single universal resource that can become depleted have developed (Inzlicht & Friese, 2019).

An alternative model is *the shifting priorities model* (Inzlicht, Schmeichel & Macrae, 2014; Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017); which infers that self-control exertion prompts a shift in attentional and motivational foci, resulting in reductions in physical performance on subsequent tasks (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017). Shifts in attentional or motivational processes are suggested to compel individuals to pursue proximal temptations (e.g., alleviating pain) and seek alternative behaviors (e.g., quitting an isometric handgrip task). Assumptions of this model are in consonance with the *opportunity-costs conceptualization* of self-control, whereby the benefit of pursuing a specific task is weighed up against its cost (Kurzban et al., 2013; Wolff & Martarelli, 2020).

A movement towards a mechanistic explanation of self-control failures has recently led to an investigation into the variables that may underpin the effects of self-control exertion on subsequent physical performance (Chapter Two). Recent research has highlighted individuals’ perceptions of pain and motivation as two plausible mechanisms. For example, following an initial exertion of self-control, participants reported higher perceptions of pain and reduced motivation during the early stages of a wall-sit task. Participants also quit the wall-sit task sooner when they did not initially exert self-control (Boat, Atkins, Davenport & Cooper, 2018; Boat & Taylor, 2017). Aligned with the assumptions of *the shifting priorities model* (Inzlicht et al., 2014), it can be suggested that once self-control has become depleted, individuals’ attentional foci shift to become focused on feelings of physiological discomfort (i.e., pain), causing shifts in motivational foci towards proximal goals (e.g., quitting or reducing effort to alleviate discomfort and pain), and away from the distal goal (e.g., persisting on the task to achieve optimal performance). Specific to motivation, it has been suggested that more nuanced aspects of motivation, such as task importance, may be a suitable underpinning mechanism that may explain self-control failures (Brown & Bray, 2019). In addition, individuals' ratings of perceived exertion (RPE) have been investigated as a potential underpinning mechanism (e.g., Wagstaff, 2014). However, the evidence base regarding the effects of self-control exertion on RPE are limited and often inconsistent (Chapter Two). Therefore, further examination of perceptions of pain, motivation, and RPE are necessary to strengthen the evidence base regarding these mechanisms, and to develop a better understanding of how self-control exertion affects subsequent endurance performance.

Considering the negative effects of self-control exertion on subsequent physical performance, there is a demand for intervention strategies to reduce these effects (Englert, 2019). One proposed intervention is goal priming, which involves providing external cues to individuals, which consequently cause changes in cognition and behavior, often without conscious intention or awareness (Papies, 2016). Goal priming has previously been shown to attenuate the effects of prior self-control exertion on subsequent task performance in a non-exercise setting (i.e., saving money; Walsh, 2014). Furthermore, in relation to the aforementioned mechanisms, providing a goal prime related to self-control has the potential to shift attentional and motivational foci away from proximal temptations that induce self-control conflict, and instead towards the distal goal (e.g., saving money; Inzlicht et al., 2014; Walsh, 2014).

However, the potential for goal priming to attenuate the effects of self-control depletion during a physical task, and the mechanisms underpinning these effects, remain unexplored. Goal priming has been used during a physical task to produce higher levels of effort and performance during endurance-based tasks (e.g., Blanchfield, Hardy, Marcora, 2014; Takarada & Nozaki, 2018). However, participants were not subject to any cognitive exertion manipulations prior to performance. Given the tenants of *the shifting priorities model* (Inzlicht et al., 2014) and previous goal priming research (Walsh, 2014), it seems reasonable to suggest that following the exertion of self-control, a self-control goal priming intervention could offset the shifts in attentional and motivational foci away from proximal temptations (e.g., feelings of discomfort and quitting the task) and encourage attainment of the distal goal (e.g., optimal performance) during a subsequent physical performance task.

Therefore, the aims of the current study were to determine: a) whether exerting self-control affects cycling TTE performance; b) whether exerting self-control increases perceptions of pain and RPE, and decreases motivation and task importance; c) the potential for a goal priming intervention to attenuate any decrements in performance due to self-control depletion. Considering the extensive self-control literature (e.g., Boat et al., 2020; Boat et al., 2021; Brown et al., 2020), it was hypothesized that prior self-control exertion on a cognitively demanding task (i.e., incongruent Stroop task) would result in reduced cycling TTE (hypothesis 1), as well as increased perceptions of pain and RPE, and reduced motivation and task importance (hypothesis 2) during the endurance task, compared to a control condition (i.e., congruent Stroop task). Finally, given the evidence base (e.g., Blanchfield et al., 2014; Takarada & Nozaki, 2018; Walsh, 2014), it was hypothesized that providing a goal priming intervention would attenuate the effects of prior self-control exertion on subsequent physical performance (hypothesis 3).

Methods

Participants

Fifteen recreationally active males (age 23 ± 3 years, height 183 ± 8 cm, mass 81 ± 10 kg, $\dot{V}O_2$ peak 41.8 ± 7.9 $ml.kg^{-1}.min^{-1}$) participated in the current study. All participants were healthy, as determined by a university approved general health questionnaire (see Appendix 3), and reported exercising on average 4 days (*SD* = 2 days) per week. A power calculation (G*Power version 3.1; Faul, Erdfelder, Lang & Buchner, 2007) with power = 0.95 and α = 0.05, specified a minimum sample size of N = 14 would be satisfactory to detect a medium effect size (0.40), which is representative of previous studies that have examined the effects of self-control exertion on subsequent performance (Brown et al., 2020).

Approval to commence data collection was provided by a university ethics committee. Each participant signed an informed consent (see Appendix 14) form after the study was described in full and it was explained that participation was anonymous and voluntary (see Appendix 15 for participant information sheet). In addition, participants were instructed to avoid vigorous exercise, and to not consume any alcohol/caffeine during the 24 h prior to the experimental trials. Participants were also asked to arrive to the laboratory 3 h postprandial. Adherence to these requirements were checked for all participants via verbal confirmation and food diaries acquired on arrival to the laboratory (see Appendix 16).

Procedures

The current study involved four laboratory visits in total. Participants completed a preliminary fitness test and were familiarized with the experimental procedure during the familiarization session (visit 1). Visits 2-4 comprised the experimental trials. Participants completed either a non-self-control exertion task (congruent Stroop) or self-control exertion task followed by a subsequent TTE cycling task. During the TTE participants were exposed to a goal priming sequence (intervention condition) or a random letter sequence (control condition) via video. Participants completed the TTE cycling task on three separate occasions: self-control depletion/goal priming condition, self-control depletion/control condition, and non-self-control depletion/control condition. The study employed a single-blind, randomized, cross-over design, and each experimental trial was separated by at least 72 h. All instructions to participants were delivered from a pre-prepared script to reduce the variability in the delivery of the instruction (Dorris, Power & Kenefick, 2012).

Preliminary Fitness Test and Familiarization.

At least one week before the experimental trials began, participants completed an incremental-effort cycle test to volitional exhaustion to establish individuals $\dot{V}O_2$ peak ($ml.kg^{-1}.min^{-1}$). This test was completed on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands) with adjustable saddle height and handle-bar position. All ergonomic aspects were recorded and replicated for all subsequent trials. Following a self-selected warm up, participants began cycling at 95 W for 3 min, followed by incremental steps of 35 W every 3 min until exhaustion. During the final min of each 3 min stage of the test, participants breathed expired air into a Douglas Bag, which was later analyzed on a Servomex 1440 Gas Analyser (Servomex, United Sates) to calculate $\dot{V}O_2$ ($ml.kg^{-1}.min^{-1}$). Participants RPE (Borg, 1998) and heart rate (measured with a live monitor; Polar Unite, Kempele, Finland) were also recorded in the final minute of each 3 min stage. During this test only, verbal encouragement was given throughout the test to ensure that participants worked to the point of volitional exhaustion. These procedures have been supported and previously employed in endurance-based research (e.g., Dring et al., 2019). From this, the relationship between power output and $\dot{V}O_2$ was determined, which was subsequently used to determine the power output reflective of 80% $\dot{V}O_2$ peak; this was used as the power output for the subsequent TTE trials.

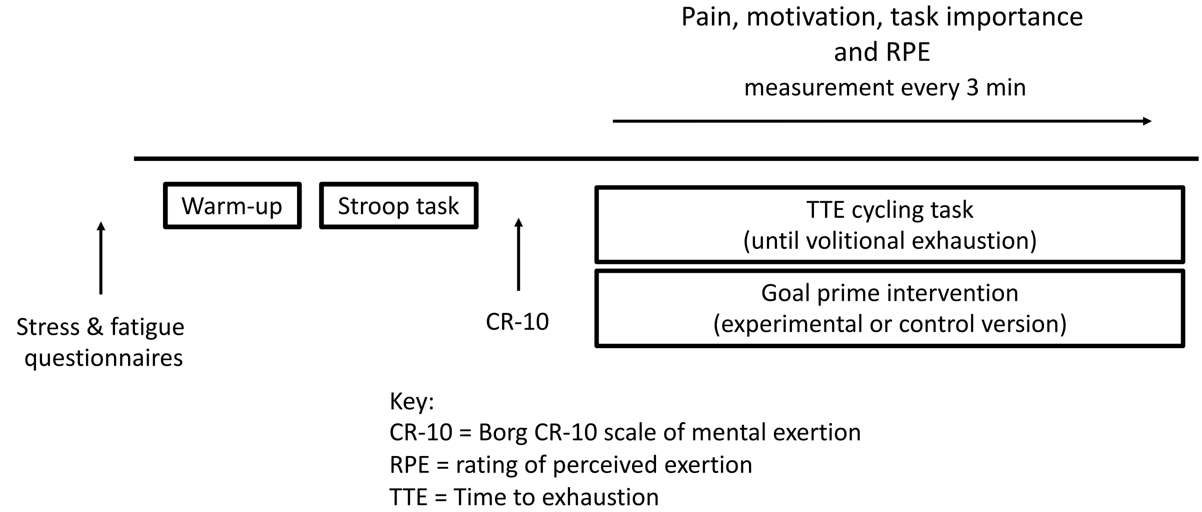
Following a standardized 30 min rest period, participants were familiarized with all components of the experimental trials (see experimental protocol section). Participants completed all questionnaires (see measures section) and the time to exhaustion (TTE) cycling task to be used during visits 2-4. A TTE cycling protocol was selected over a time-trial cycling protocol as previous research has demonstrated that prior self-control exertion does not appear to negatively impact overall time-trial cycling performance (e.g., Boat et al., 2021). Participants were also shown a control version of the scanning visual vigilance task (see scanning visual vigilance task section) while they completed the TTE cycling task.

Experimental Protocol

The experimental protocol can be found in Figure 5.1. Participants were instructed to keep a record of their food intake and activity patterns prior to the first TTE cycling task and to replicate the same diet and exercise activities 24 h before all subsequent trials (see appendix 16). Each participant took part in three experimental sessions: non-self-control exertion (congruent Stroop task) with no goal prime intervention (control condition), self-control exertion (incongruent Stroop task) with no goal prime intervention, and self-control exertion (incongruent Stroop task) with goal prime intervention. On arrival at the laboratory, participants completed questionnaires to assess daily stress and fatigue (see measures section). Previous research has recognized the potential for stressful events and feelings of fatigue to reduce an individual's self-control strength, therefore it was important to control for both variables in the current study (Englert & Rummel, 2016; Graham, Martin Ginis & Bray, 2017; Tangney et al., 2004).

Figure 5.1

Experimental protocol demonstrating the timing of each measurement during the experimental trials.



The cycle ergometer was then adjusted to the pre-recorded ergonomic measurements. Participants began a standardized warm-up consisting of 3 min at a power output reflective of 40% $\dot{V}O_2$ peak, followed by 2 min at 60% $\dot{V}O_2$ peak. Immediately following the warm-up, participants were required to complete either a self-control depletion or non-self-control depletion experimental manipulation for 4 min. A modified Stroop task (Stroop, 1935) was utilized as the method of depleting individuals' self-control. This task has frequently been used in similar self-control exertion studies (e.g., Boat et al., 2020; Englert & Wolff, 2015; McEwan et al., 2013). Furthermore, this duration (4 min) of the Stroop task was utilized as previous research has demonstrated negative effects on subsequent physical performance following a 4 min Stroop task (e.g., Boat & Taylor, 2017; Boat et al., 2020). The Stroop task was completed on a laptop computer, with a head-to-monitor distance of 80–100 cm, via custom-made software (SuperLab 6.0) with words serially presented on the screen. Participants were instructed to respond as accurately and quickly as possible. Stimuli remained on the screen until participants responded. There was an inter-stimulus interval of 1 s. Prior to the actual test, participants completed a practice session lasting 30 s to familiarize themselves with the task and response pad.

In the Stroop task, a word (always a color) was displayed in the center of a computer screen, and participants were required to select the response pad button that matched the color of the print ink. In the congruent version of the Stroop task (non-self-control exertion), the word and color were matched (e.g., the word “green” was printed in green ink). In the incongruent version of the Stroop task (self-control exertion), the printed text and print ink color were mismatched. For example, if the word “green” was printed in yellow ink, the correct keypad response would be the yellow button. The incongruent version of the Stroop task has frequently been shown to be a cognitively challenging task that requires self-control, whereby participants are required to volitionally overrule their initial impulse to select the ink color, as opposed to the word (e.g., Boat et al., 2020; Englert & Wolff, 2015; McEwan et al., 2013). Immediately following the Stroop task, participants mental effort during the cognitive task was assessed using Borg’s (1998) CR-10 mental exertion questionnaire (see measures section).

Immediately following the completion of the questionnaires, participants performed the TTE cycling task and were exposed to the scanning visual vigilance task (see measures section). The Lode cycle ergometer was set to hyperbolic mode and at a power output reflective of 80% $\dot{V}O_2$ peak (calculated as previously described). Participants were informed that the pedal frequency could be chosen freely between 60 and 100 revs·min^{-1} (recorded every 3 min). Time to exhaustion was measured from the start of the TTE cycling task until the pedal frequency fell below 60 revs·min^{-1} for a second time, following one verbal warning for an initial violation of the pedal frequency; or at the point of volitional exhaustion. During the TTE cycling task, participants were instructed to watch a video on the screen in front of them, through which the goal prime intervention was delivered (see scanning visual vigilance task and goal prime section). The video started when participants began the TTE cycling task and ended when they terminated the task. In addition, verbal measurements of participants perceptions of pain, motivation, task importance, and RPE were taken every 3 min (see measures section). Other than obtaining participant’s perceptions, there was no interaction between the experimenter and the participant as they completed the TTE cycling task. Following the final experimental trial, participants completed a study feedback questionnaire (see measures section) to gauge whether the goal prime had been detected.

In sum, participants performed three TTE cycling task under three experimental conditions: non-self-control exertion (congruent Stroop task) with no goal prime intervention (control condition), self-control exertion (incongruent Stroop task) with no goal prime intervention, and self-control exertion (incongruent Stroop task) with goal prime intervention. The order of the sessions was counterbalanced.

Measures

Daily Stress. The Daily Inventory of Stressful Events Questionnaire (Almedia, Wethington & Kessler, 2002) consists of seven statements that asks participants to report whether any number of stressful events had occurred today by circling either "yes" or "no" (e.g., "Anything at home that most people would consider stressful"). This questionnaire has frequently been used to measure daily stress (e.g., Boat et al., 2020) and has been shown to have high internal consistency and predictive validity (Almeida et al., 2002) (see Appendix 6).

Perceptions of Physical Fatigue. Physical fatigue was assessed using two modified items from the fatigue subscale of the Profile of Mood States (i.e., "I feel physically exhausted and "I feel physically worn out"; McNair, Lorr & Droppleman, 1992). Participants were required to rate their agreement with each item on a five-point scale (1 = not at all true; 5 = very true). These items have demonstrated high factor loadings and acceptable reliability in previous research (Boat & Taylor, 2017) (see Appendix 7).

Mental Exertion. Borg's single-item CR-10 scale (Borg, 1998) was employed to measure participants mental exertion following the Stroop task (0 = extremely weak; 10 = absolute maximum). This questionnaire has been used extensively in self-control research, with higher scores demonstrating higher perceived mental exertion (e.g., Boat et al., 2021; Steel, Bishop & Taylor, 2021) (see Appendix 8).

Perceptions of Pain, Motivation, and Task Importance. Participants' perceptions of pain, motivation, and task importance were measured on a 1–20-point scale which assessed their current feelings for each item. For example, perception of pain was measured by responding to the statement "please rate your current level of pain experienced during this trial" (1 = no pain; 20 = worst possible pain); motivation was assessed by responding to the statement "please rate how motivated you are to continue exerting the effort required to rotate the pedals" (1 = I have zero motivation; 20 = I am fully motivated); task importance was measured by responding to the statement "please rate the importance of completing the TTE cycling task for as long as possible" (1 = not important at all; 20 = extremely important). Previous research has used comparable methods to measure participants task importance during a physical task (Taylor, Smith & Hunte, 2020), and single-measure items are frequently used in self-control research to measure perceptions of pain and motivation (e.g., Boat et al., 2021; Stocker et al., 2020). Due to the demands of the physical task, responses were collected verbally (see Appendix 17).

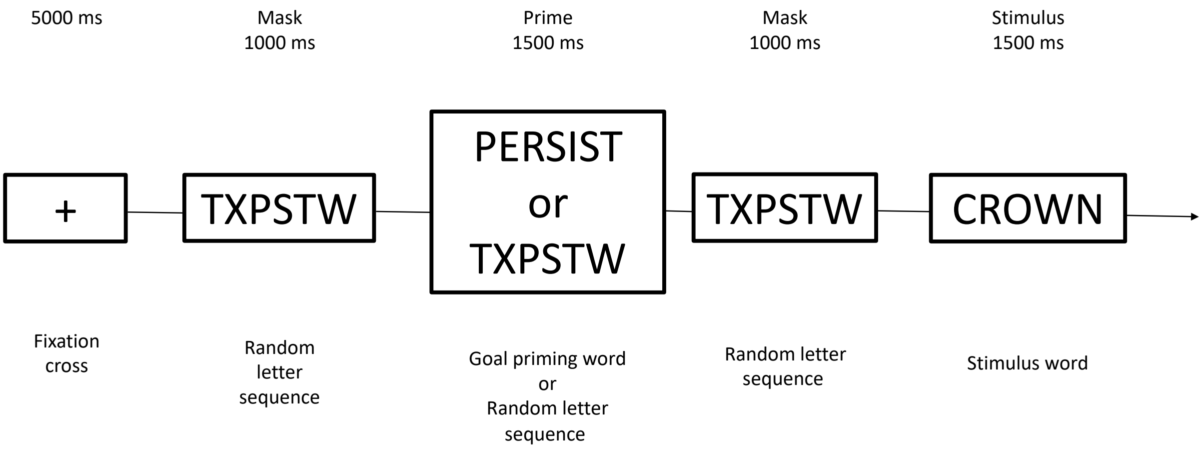
Ratings of Perceived Exertion (RPE). Participant's RPE was measured verbally using a 1–20-point Borg scale (1 = no exertion at all; 20 = extremely hard) (Borg, 1998) (see Appendix 17).

Scanning Visual Vigilance Task. To deliver the goal prime intervention during the TTE cycling task, a scanning visual vigilance task was used (Lieberman, 1998). Participants were instructed to always focus on the projector screen in front of them. They were told that they were going to be presented with a series of word sequences and that during this sequence a stimulus word will always be presented. They were further instructed that the stimulus word would sometimes be presented with a 2 cm black circle either above or below it at random. Participants were asked to continue cycling whilst maintaining their focus on the screen and acknowledge to themselves when the circle appeared. However, no response was required when the circle appeared. The time that elapsed between each appearance of the circle was no shorter than 10 s and no longer than 30 s (Blanchfield et al., 2014). Similar protocols have been used in previous research to deliver goal priming sequences, because of the low additional cognitive demands imposed upon participants during physical activity (e.g., Blanchfield et al., 2014).

Goal Priming Procedure. Participants were exposed to supraliminal goal primes during the scanning visual vigilance task (see Figure 5.2). Supraliminal primes were selected as they have been shown to have greater and longer-lasting effects on behavior, compared to subliminal primes (Francken, van Gaal & de Lange, 2011). One prime was presented sequentially every 10 s. Each prime sequence consisted of a white fixation cross that was displayed on a dark grey background in the center of the projector screen for 5000 ms. This was instantly followed by a 1000 ms presentation of a random letter string (e.g., TXPSTW) that acted as a forward mask. This was followed by a 1500 ms presentation of our goal prime intervention, or a random letter string (no goal prime intervention). Specifically, the goal prime intervention condition consisted of five phrases related to positively utilizing self-control (determination, exert, continue, maximal effort, persist and sustain). This was followed by another 1000 ms presentation of a random letter string that acted as a backward mask. Finally, a neutral stimulus word (e.g., Crown), with or without a black circle above or below, was displayed for 1500 ms. Based on previous recommendations (Silvestrini & Gendolla, 2011), it was suggested that one third of the prime sequence should consist of a goal prime. Thus, it was ensured that out of every six prime sequences, two consisted of self-control phrases and the remaining four consisted of random letter strings. This was to avoid habituation to the self-control phrases (Blanchfield et al., 2014; Silvestrini & Gendolla, 2011). In the no goal prime intervention condition, no self-control phrases were presented, instead, only random letter strings were presented until the neutral stimulus word, with or without a black circle above or below it, was presented (see Figure 5.2). The priming sequence was generated in PsychoPy software (Peirce et al., 2019) and the primes were presented on a 13' laptop screen with an aspect ratio of 16:10, a refresh rate of 60 Hz, and a 1440 x 900-pixel display. From this laptop, the primes were projected onto a 175" screen via a HDMI cable. Similar priming protocols have been used in previous research also employing a physical endurance task (Blanchfield et al., 2014; Takarada & Nozaki, 2018).

Figure 5.2

Goal priming procedure.



Study Feedback. A study feedback questionnaire was administered as a manipulation check to determine if participants were aware that they had received the goal priming intervention. This one-item questionnaire required participants to answer "yes" or no" to the following statement: "during the video, did you recall seeing any words related to performance?". This procedure was implemented due to recommendations in previous goal priming studies (e.g., Bargh & Chartrand, 2000, Blanchfield et al., 2014). Participants completed the questionnaire at the end of each TTE cycling task (see Appendix 18).

Task performance. Performance was measured using the time (in s) participants quit the TTE cycling task. Terminating the TTE cycling task was considered as the moment participants fell under 60 revs·min^{-1} for a second time, following one verbal warning from the investigator; or at the point of volitional exhaustion. Participants cycling cadence (revs·min^{-1}) was also recorded every 3 min to assess participants effort.

Statistical Analysis

Data were analyzed using SPSS (version 24; SPSS Inc., Chicago, IL, United States). To check for baseline differences between the trials, stress, fatigue, mental exertion, and Stroop task performance were analyzed using one-way repeated measures analysis of variance (ANOVA), with Bonferroni-corrected paired samples t-tests used as post hoc testing where significant differences existed. TTE cycling task performance, mechanisms (perceptions of pain, motivation, task importance, and RPE), and cadence were also analyzed using one-way repeated measures ANOVA (with Bonferroni-corrected paired samples t-tests as post hoc testing, with effect sizes calculated as Cohen's *d*). Previous research has suggested that self-control exertion may negatively impact both initial and overall perceptions (Chapter Two). Therefore, separate ANOVA analyses were conducted for both initial (i.e., after 3 min) and overall (i.e., average of scores) measurements for potential mechanisms. All data are reported as mean ± standard deviation and 95% CI. Statistical significance was accepted as $p < 0.05$.

Results

Preliminary Manipulation Checks

Table 5.1 displays descriptive statistics for each variable across each experimental condition. There was no difference at baseline between the trials for stress ($F(2,26) = 1.44$, $p = 0.26$), or fatigue ($F(2,26) = 1.13$, $p = 0.86$), therefore, it was not necessary to control for these variables. There was a significant difference in participants level of mental exertion between each condition ($F(2,26) = 23.22$, $p = 0.001$). Upon further inspection, mental exertion was significantly lower on the non-self-control with no goal prime intervention condition (2.71 ± 1.38, 95% CI: 1.91 – 3.51) compared to all other trials (self-control exertion with goal prime intervention condition: 5.53 ± 1.87, 95% CI: 4.35– 6.51, $t(13) = -5.24$, p = 0.001, $d = 1.65$; self-control exertion with no goal prime intervention condition: 5.93 ± 1.77, 95% 4.90 – 3.51, $t(13) = -6.11$, $p = 0.001$, $d = 2.02$). In addition, this was supported with differences in Stroop task performance. There were significant differences in participants' response time ($F(2,26) = 4.38$, $p = 0.02$). Upon further inspection, participants responded quicker in the non-self-control with no goal prime intervention (1593 ± 270 ms, 95% CI: 1430 – 1757) compared to all other trials (self-control exertion with goal prime intervention condition: 1822 ± 312 ms, 95% CI: 1634 – 2012, $t(13) = -2.36$, $p = 0.04$, $d = 0.77$; self-control exertion with no goal prime intervention condition: 1829 ± 305 ms, 95% CI: 1644 – 2013, $t(13) = -2.34$, $p = 0.04$, $d = 0.82$). Furthermore, there was significant differences in participants' response accuracy between each condition ($F(2,26) = 4.52$, $p = 0.03$). Upon further inspection, participants responded with more accuracy in the non-self-control exertion with no goal prime intervention condition (99.2 ± 0.9%, 95% CI: 98.7 – 99.7) compared to the self-control exertion with no goal prime intervention condition (98.1±1.7%, 95% CI: 97.1 – 99.1, $t(13) = 2.57$, $p = 0.02$, $d = 0.80$). However, there was no significant difference between the non-self-control exertion with no goal prime intervention condition and self-control with goal prime intervention condition (98.7±1.3%, 95% CI: 98 – 99.5, $t(13) = 1.39$, $p = 0.19$, $d = 0.45$). Finally, the study feedback questionnaire demonstrated that the goal prime intervention was successfully detected with 100% of participants answering "yes" to seeing performance related words in the goal prime intervention condition. In addition, all participants answered "no" in the no goal prime intervention conditions.

Table 5.1

Descriptive statistics for mental exertion, daily stress and fatigue (data are mean ± SD).

	Experimental Condition		
	Self-control exertion with goal prime	Self-control exertion without goal prime	Non-self-control exertion without goal prime
Mental Exertion	5.43 ± 1.87	5.93 ± 1.77	2.71 ± 1.38 **
Daily Stress	0.71 ± 0.99	0.86 ± 1.46	0.36 ± 0.63
Fatigue	3.93 ± 1.64	4.14 ± 1.99	4 ± 1.41

** main effect of trial $p < 0.001$

TTE Cycling Task Performance

There was no statistically significant difference in overall TTE cycling task performance between the three experimental conditions ($F(2,26) = 1.35$, $p = 0.28$; Table 5.2).

Perceptions of Pain, Motivation, and Task Importance

There was no statistically significant difference in participants' overall perceptions of pain ($F(2,26) = 1.06$, $p = 0.36$), overall motivation ($F(2,26) = 1.68$, $p = 0.21$), or overall task importance ($F(2,26) = 0.34$, $p = 0.67$) between the experimental trials (Table 2).

Furthermore, there was no statistically significant difference in participant's initial perceptions of pain ($F(2,26) = 2.25$, $p = 0.13$), initial motivation ($F(2,26) = 0.54$, $p = 0.59$) or initial task importance ($F(2,26) = 0.08$, $p = 0.98$) between the experimental trials (Table 5.2).

RPE

There was no statistically significant difference in participants' overall RPE during the TTE cycling task between the experimental trials ($F(2,26) = 1.01$, $p = 0.38$). In addition, there was no statistically significant difference in participants' initial RPE ($F(2,26) = 1.39$, $p = 0.27$) between the experimental trials (Table 5.2).

Cadence

Overall, participant's average cycling cadence was significantly different between the trials ($F(2,26) = 9.19$, $p = 0.001$). Upon further inspection, cycling cadence was significantly higher during the self-control exertion with goal prime intervention condition (85 ± 1 $rev \cdot min^{-1}$, 95% CI: 82 – 89 $rev \cdot min^{-1}$) compared to all other trials (self-control exertion with no goal prime intervention condition: 81 ± 1 $rev \cdot min^{-1}$, 95% CI 78 – 84 $rev \cdot min^{-1}$, $t(13) = 4.21$, $p = 0.001$, $d = 0.73$; non-self-control exertion with no goal prime intervention condition: 81 ± 1 $rev \cdot min^{-1}$, 95% CI 79 – 85 $rev \cdot min^{-1}$, $t(13) = 3.66$, $p = 0.003$, $d = 0.68$). However, there was no difference in average cycling cadence between the self-control exertion with goal prime intervention condition and the non-self-control exertion with no goal prime intervention condition ($t(13) = 0.47$, $p = 0.65$, $d = 0.08$) (Table 5.2).

Table 5.2

Descriptive statistics for performance time, pain, motivation, task importance, ratings of perceived exertion and cadence across all trials (data are mean ± SD).

	Experimental Condition		
	Self-control exertion with goal prime	Self-control exertion without goal prime	Non-self-control exertion without goal prime
TTE Performance Time (s)	1286 ± 610	1172 ± 494	1253 ± 387
Pain			
Overall	12.06 ± 2.29	12.73 ± 2.46	12.48 ± 1.96
Initial	6.93 ± 2.99	7.57 ± 2.98	6.36 ± 2.49
Motivation			
Overall	11.04 ± 2.85	9.95 ± 2.96	6.36 ± 2.49
Initial	12.86 ± 2.77	12.14 ± 3.06	12.79 ± 3.17
Task Importance			
Overall	11.40 ± 2.66	11.13 ± 2.45	11.35 ± 2.66
Initial	13.14 ± 2.63	13.07 ± 2.37	13.14 ± 2.71
RPE			
Overall	13.03 ± 2.29	13.53 ± 2.19	12.93 ± 1.79
Initial	8.00 ± 3.28	8.10 ± 3.28	7.21 ± 2.67
Cadence ($rev \cdot min^{-1}$)	85.45 ± 5.41	81.46 ± 5.25	81.98 ± 4.91**

** main effect of trial $p < 0.01$

Discussion

The present study examined the effects of exerting self-control on a subsequent TTE cycling task, and the potential for a goal prime intervention to attenuate any decrements in performance due to prior self-control exertion. In addition, participant's perceptions of pain, motivation, task importance, and RPE were investigated to determine whether these mechanisms could explain any observed differences in performance. The main findings of the present study were that prior self-control exertion did not negatively affect subsequent TTE cycling performance. In addition, goal priming did not improve endurance performance or attenuate the effects of initial self-control exertion on subsequent physical task performance.

However, the goal prime intervention did increase participant's cycling cadence. Furthermore, prior self-control exertion and a goal prime intervention did not affect participant's perceptions of pain, motivation, task importance, or RPE.

Contrary to our hypothesis, prior self-control exertion did not affect TTE cycling task performance, despite confirmation that the manipulation of self-control was successful (via the CR10 scale and Stroop task performance). Findings conflict with previous evidence that suggests prior self-control exertion causes detriments to subsequent physical task performance (Boat et al., 2020; Boat et al., 2021; Englert & Wolff, 2015; O'Brien et al., 2020; Wagstaff, 2014). One explanation for this finding could be due to the lack of pacing required for a TTE cycling task. Previous research has demonstrated that prior self-control exertion may interfere with self-regulatory pacing strategies during the early stages of a cycling task, resulting in decrements to cycling time-trial performance (Boat et al., 2017; Boat et al., 2021). However, such pacing strategies are not required in the present study given that participants were not required to monitor exercise intensity during the TTE cycling task (Wagstaff, 2014). Therefore, by the time participants decided to quit the TTE cycling task (on average ~ 20 min), the effects of prior self-control exertion may have diminished (Baumeister et al., 1998; Walsh, 2014).

Future research should examine the time course of self-control replenishment to understand exactly how long the effects of self-control exertion are detrimental to performance.

Another key finding of the present study was that perceptions of pain, motivation, task importance, and RPE were unaffected by prior self-control exertion. This finding is contrary to previous research which suggests that self-control exertion results in higher perceptions of pain and RPE, and lower motivation and task importance (Boat et al., 2018; Boat et al., 2020; Boat & Taylor, 2017; Brown & Bray, 2019; Wagstaff, 2014). One plausible explanation may be the difference in time-points at which the mechanistic measurements were obtained. In previous research, differences in initial mechanistic measures have been found when measurements were obtained at 30 s (e.g., Boat et al., 2018; Boat et al., 2020; Boat & Taylor, 2017), whereas, in the present study measurements of mechanisms were recorded at 3 min. From a shifting priorities model perspective (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), it could be suggested that after 3 min, initial shifts in attentional and motivational foci had elapsed, resulting in initial perceptions of pain, motivation, task importance, and RPE plateauing. Future research should determine exactly when attentional and motivational priorities shift towards proximal temptations (Boat et al., 2018; Milyavskaya & Inzlicht, 2017). This will provide further understanding into the mechanisms that underpin the effects of self-control exertion on subsequent physical performance, which is pivotal to inform the design of future interventions aimed at attenuating the effects of prior self-control exertion.

Based on previous research in non-exercise settings (Blanchfield et al., 2014, Takarada & Nozaki, 2018; Walsh, 2014), it was hypothesized that goal priming would attenuate the effects of prior self-control exertion on subsequent physical task performance. The present study did not find support for this hypothesis. Although all participants reported detecting the goal prime (as assessed by the study feedback questionnaire) and steps were taken to reduce cognitive demand during the scanning visual vigilance task, it is possible that instructing participants to maintain focus on a video whilst cycling placed equivalent demand on self-control processes throughout each experimental condition. Future research could attempt to provide the goal prime before, or in preparation, for the performance task. This approach may reduce the cognitive demand during the physical task and ensure that the goal prime intervention is still delivered close to the “critical situation” where behavior change must take place (i.e., exerting additional self-control to override the discomfort and strive for optimal performance) (Papies, 2016).

Whilst findings did not support our hypothesis regarding TTE cycling task performance, goal priming increased participants’ cycling cadence. Even in a self-control depleted state, participants cycled at a higher cadence when exposed to the goal prime intervention when compared to the other experimental trials. These findings are in accordance with previous research that has found goal priming can generate higher levels of effort and performance during endurance-based tasks (Blanchfield et al., 2014; Takarada & Nozaki, 2018). Future research should continue to explore the impact of visual cues during physical performance tasks, following self-control depletion, to ultimately inform the design of interventions to enhance endurance performance.

Limitations and Future Research Directions `

Methodologically speaking, a strength of the present study is that a within-subjects design was employed, controlling for participants individual differences. Furthermore, the current study measured multiple mechanisms simultaneously, enabling a comprehensive investigation of the potential mechanisms that underpin self-control exertion.

However, the present study is not without limitation. For example, to assess the potential mechanisms underpinning the effects of prior self-control exertion, findings relied on self-report data. Previous research has suggested that mechanisms may not be shown to influence physical performance when assessed by self-report (Stocker et al., 2020). However, perceptions of pain and motivation have both previously been shown to mediate the effects of self-control exertion when assessed by a self-report visual analogue scale (VAS) (Boat & Taylor, 2017; Boat et al., 2018). A movement towards more objective measures of potential mechanisms (e.g., electroencephalogram to measure motivational process; Schmeichel, Crowell & Harmon-Jones, 2016) could be employed to further investigate the underpinning mechanisms of self-control exertion during physical performance.

Finally, although employing the Stroop task for 4 min has been shown to be an adequate amount of time to deplete participants self-control (e.g., Boat et al., 2018), increasing the duration of the initial self-control exertion task may have resulted in a detrimental effect on subsequent TTE cycling task performance (Hagger et al., 2010; Boat et al., 2020). Moreover, spending longer on the initial self-control task could result in greater changes in potential mechanisms, such as increasing perceptions of pain and reducing motivation (Boat et al., 2020). Future research should thus continue to investigate the impact of initial task duration on subsequent shifts in attentional and motivational foci, and their implications for subsequent physical performance.

Conclusion

The present study provides evidence that initial self-control exertion and a goal prime intervention do not affect performance on a subsequent TTE cycling task. Furthermore, self-control exertion and a goal prime intervention did not lead to shifts in attentional and motivational foci during a subsequent physical endurance task. However, goal priming did increase participants cycling cadence, with participants cycling at a higher cadence in the self-control exertion and goal priming intervention condition when compared to all other conditions without the goal prime. Finally, debates regarding the exertion of self-control must consider that any observed effects may be dependent on the timing of performance and mechanism inspection; an area which warrants further research.

Chapter Six

General Discussion

This thesis began by investigating the effects of prior self-control exertion on subsequent physical performance, and the underpinning mechanisms for the effect under a meta-analytical lens. This meta-analysis (Chapter Two) revealed a medium effect size (g = -0.55) for the negative effect of prior self-control exertion on subsequent sporting performance, but also highlighted multiple gaps and limitations within the literature, including the need to investigate the effects of prior self-control exertion on subsequent performance during more complex sporting physical tasks. As a result, a sequential-task paradigm was employed to investigate whether the exertion of self-control impaired subsequent repeated running sprint performance (Chapter Three), as well as potential underpinning mechanisms of the effect (e.g., perceptions of pain, motivation). Building on this work, the thesis also investigated boredom as a novel mediator that may explain the effects of prior self-control exertion on subsequent physical performance (Chapter Four). Finally, goal priming was employed as a potential intervention technique to attenuate the detrimental impact of self-control exertion on subsequent physical performance (Chapter Five). This chapter presents a synthesis of the key findings, and the associated practical implications. The limitations of the current thesis will also be discussed, in conjunction with potential directions for future research.

The Effects of Prior Self-Control Exertion on Subsequent Physical Performance and the Underpinning Mechanisms of the Effect: A Meta-Analysis

Chapter Two considered the existing self-control and physical performance literature to investigate the effects of self-control exertion on subsequent physical performance. Furthermore, Chapter Two provided the first investigation into the explanatory mechanisms underpinning the effects of self-control exertion on subsequent physical performance under a meta-analytical lens. The findings demonstrated a statistically significant medium sized negative effect of prior self-control exertion on subsequent physical performance (g = -0.55). This finding extends the empirical (e.g., Boat et al., 2020; Boat, Sunderland & Cooper, 2021; Dorris et al., 2012; Wagstaff, 2014) and meta-analytical (e.g., Brown et al., 2020) research corroborating the negative effect of prior self-control exertion on subsequent physical performance. It is noteworthy that the results of Chapter Two yielded a higher effect size (g = -0.55) when compared to previous meta-analytical work (e.g., Brown et al., 2020; g = -0.45). The differences between the effect sizes could be attributed to the inclusion of unpublished studies in the meta-analysis of Brown et al. (2020), therefore, greater influence of the 'file drawer effect', in which null effect sizes may reduce the overall effect size. Furthermore, mechanistically Chapter Two revealed a small increase in initial perceptions of pain ($g = 0.18$) and a medium sized reduction in self-efficacy ($g = -0.48$); suggesting that these may be key mechanisms underpinning the negative effects of prior self-control exertion on subsequent physical performance.

In view of these findings, three key areas for future research were highlighted. First, while support for the negative impact of prior self-control exertion on subsequent physical performance was established, it is evident that performance task type is an important factor that may determine study outcomes. Consequently, it was suggested that the prior exertion of self-control may have a greater detrimental effect on subsequent physical performance in isometric tasks (e.g., wall-sit), compared to whole-body endurance tasks (e.g., cycling) (Giboin & Wolff, 2019). However, it was clear that certain performance task types were underrepresented in the current literature. For instance, there was a lack of: a) endurance physical tasks and b) sport-specific performance tasks that have been employed. As a result, further research applying different physical performance tasks (i.e., repeated running sprint performance) was required to advance the evidence base and to enhance our understanding of the effects of prior self-control exertion on subsequent physical performance.

Second, there were several underpinning mechanisms to explain the effects of prior self-control exertion on subsequent physical performance that required further investigation. The meta-analysis (Chapter Two) provided no evidence that prior self-control exertion affected underpinning mechanisms including motivation and RPE (g = -0.03; g = 0.03, respectively), however, it is possible that this may be due to inconsistences in methodologies across the included studies within the meta-analysis. In addition, novel mechanisms such as perceptions of boredom, sustained attention, and more nuanced measurements of motivation (e.g., goal commitment) warranted investigation, but could not be included in the meta-analysis due to a lack of available evidence. Therefore, further research into the underpinning mechanisms of self-control were required. Finally, given the negative impact of self-control exertion on subsequent physical performance, it highlighted the necessity for the development of interventions to attenuate the effects of prior self-control exertion on subsequent physical performance. Therefore, following Chapter Two, attention shifted to address these three key gaps in the literature.

Self-Control Effects are Variable Depending on Task Type

A particular strength of the current thesis is the attention afforded to the examination of performance effects across various types of physical performance tasks. The meta-analysis conducted in Chapter Two demonstrated that the effect size of prior self-control exertion on subsequent physical task performance differed considerably depending on the type of physical task employed. Specifically, the largest negative effect sizes were found for isometric ($g = -0.62$) and dynamic ($g = -0.61$) physical tasks, while smaller negative effect sizes were found for aerobic ($g = -0.36$) and motor skill ($g = -0.45$) physical tasks. Extending the meta-analytical evidence, the subsequent chapters of this thesis aimed to employ various physical tasks to investigate the capability of self-control to have differing effects dependent on physical task type. Chapter Three and Five employed endurance-based task types (Chapter Three, repeated sprint task; Chapter Five, TTE cycling task), while Chapter Four employed an isometric measure of physical task performance (wall-sit task). Chapter Four provided further support for previous findings that the prior exertion of self-control (via a cognitively demanding task) impairs subsequent physical performance (e.g., Boat et al., 2020; Boat et al., 2021; Bray, Oliver, Graham & Martin Ginis, 2013; Englert & Wolff, 2015; O'Brien, Parker, Moore & Fryer, 2020; Wagstaff, 2014). However, contrary to our hypothesis, Chapter Three and Chapter Five revealed that prior self-control exertion did not negatively impact subsequent physical task performance on endurance-based tasks. While findings do not support recent meta-analytical evidence (e.g., Brown et al., 2020), the findings of the current thesis suggest that rather than the concerns regarding the existence of the ego-depletion effect (e.g., Carter et al., 2015; Wolff, Baumann & Englert 2018), null findings could potentially be a result of the task type that is employed. The current thesis presents strong evidence for the notion that prior self-control exertion has a greater detrimental effect on subsequent physical performance in isometric tasks (e.g., wall-sit task) compared to whole body endurance tasks (e.g., cycling task) (Giboin & Wolff, 2019).

One explanation for the discrepancy in the ego-depletion effect between performance task domains could be the level of decision making required for each physical task. Previous research has suggested that the exertion of self-control is a result of a conscious decision-making process to resist temptations and purse long-term goals (Knoch & Fehr, 2007). Thus, it is proposed that isometric tasks, such as the wall-sit task until volitional exhaustion, required an active decision to quit the task when the discomfort of the task outweighed the importance of optimal performance (Boat et al., 2018; Kurzban et al., 2013). In comparison, the endurance-based physical tasks employed in Chapter Three and Chapter Five required limited conscious decision making. Specifically, in Chapter Three, the repeated sprint task did not require the participant to continually exert effort over a prolonged period of time, therefore, there was no conscious decision regarding when to quit the repeated sprint task. In addition, the TTE cycling task employed in Chapter Five did not require participants to make any decisions regarding pacing strategies during the cycling task. As a result, the current thesis infers that physical performance decrements, following the exertion of self-control, are a result of the negative impact that prior self-control exertion has on individuals' decision-making processes during the physical task.

Taken together, the findings from Chapters Three, Four, and Five have important implications for self-control theory. First, it is recommended that when examining the effects of self-control exertion on subsequent physical performance, task type must be carefully considered during study design and subsequent interpretation of findings. Moreover, when investigating the underpinning mechanisms of self-control exertion on subsequent physical performance, it may be beneficial to employ isometric or dynamic physical tasks which may be more susceptible to the negative effects of prior self-control exertion. This may allow for the measurement of underpinning mechanisms to be more sensitive to identifying shifts in attentional and motivational processes. Second, future research should isolate the decision-making process during a physical task and target this in self-control interventions. For instance, previous research has demonstrated that prior self-control exertion may interfere with self-regulatory pacing strategies during the early stages of a cycling task, resulting in decrements to cycling time-trial performance (Boat et al., 2017; Boat et al., 2021). Therefore, interventions could aim to target and improve initial pacing strategies to attenuate any negative effects of self-control exertion. To continue informing sport psychology practitioners, further studies investigating the effects of self-control exertion on subsequent physical performance are necessary to highlight performance task types that are susceptible to the negative impact of prior self-control exertion. In addition, improving our understanding will aid the design and development of sport-specific self-control interventions to attenuate these negative effects.

Self-Control May Replenishment Over Time

Chapters Three, Four and Five of the current thesis consistently demonstrated that the detrimental effects of self-control exertion are liable to dimmish over time. In Chapter Three, performance decrements were not observed during the repeated sprint task when participants had a period of rest between each sprint. In addition, when the time between completing the incongruent Stroop task and measurements of self-control performance were delayed, task performance decrements were not demonstrated in Chapter Four (Rapid Visual Information

Processing Test; RVIPT) and Five (TTE cycling task). The results provide further support for previous findings that self-control can replenish following prior exertion (Baumeister et al., 2007; Masicampo, Martin & Anderson, 2014; Steinborn & Huestegge, 2016; Tyler & Burns, 2008). Although doubts remain regarding the belief that self-control capacity can be attributed to a single universal resource that can become depleted (Inzlicht & Friese, 2019), the current thesis provides an empirical base for the assumption that individuals can replenish self-control during physical performance following depletion.

Currently, research that has directly investigated the ability for self-control to replenish is relatively unexplored and especially limited in a sport and exercise setting. Conclusions drawn from Chapters Three, Four, and Five actively encourage new lines of investigation. Specifically, Chapters Four and Five suggests that there is a wash-out period where the effects of prior self-control exertion are no longer present, and self-control becomes replenished (~10 min; Tyler & Burns, 2008). The findings of Chapter Four may provide support for this suggestion, whereby the time between participants completing the incongruent Stroop task and performing the RVIPT (~10 min) may have allowed self-control to replenish, leading to optimal sustained attention (measured using the RVIPT). In addition, it is suggested that by the time participants decided to quit the TTE cycling task in Chapter Five (on average at ~ 20 min), the effects of prior self-control exertion may have diminished (Baumeister et al., 1998; Walsh, 2014). This resulted in no differences in cycling performance or differences in perceptions of pain, motivation, task importance, or ratings of perceived exertion (RPE) being observed between the self-control and non-self-control experimental conditions. Building on this, the results of Chapter Three propose that future research should investigate the potential for rest to attenuate the effects of prior self-control exertion on subsequent physical performance. It could be suggested that due to the 24 s rest period between each sprint, participants were able to sufficiently alleviate any pain experienced during the previous sprint, and restore self-control ready for the upcoming sprint (Masicampo, Martin & Anderson, 2014; Steinborn & Huestegge, 2016). These suggestions remain speculative at present; however, further research is required into the capability for rest to overcome the effects of prior self-control exertion on subsequent physical performance; and the time course over which this takes place.

In view of these proposals, it is imperative that future research exploring the effects of prior self-control exertion on subsequent physical performance must acknowledge that any observed findings may be dependent on the time-points of measurements. Researchers should continue to investigate the impact of prior self-control exertion on subsequent physical tasks of varying durations, to pinpoint the time-course in which self-control replenishes.

Underpinning Mechanisms That May Explain Why Self-Control Exertion Impacts Subsequent Physical Performance

Throughout the current thesis the potential underpinning mechanisms to explain the effects of prior self-control exertion on subsequent physical task performance were investigated. Chapter Two provided the first investigation of the underpinning mechanisms for the effect of prior self-control exertion on subsequent task performance under a meta-analytical lens. In addition, further research was conducted on established mechanisms such as perceptions of pain and motivation (Chapter Three, Four, and Five) to address inconsistent findings (e.g., Boat et al, 2020; Stocker et al., 2020). Furthermore, following suggestions in the literature (e.g., Wolff & Martarelli, 2020) the current thesis also investigated boredom as a novel mediator that may explain the effects of prior self-control exertion on subsequent physical performance (Chapter Four). The key mechanistic findings of this thesis were that self-efficacy (Chapter Two) and motivation (Chapter Three and Four) may be suitable mechanisms to explain the effects of prior self-control on subsequent task performance. In addition, findings regarding perceptions of pain remained inconsistent with mixed results demonstrated (Chapter Two, Three, Four, and Five). Furthermore, perceptions of boredom do not seem to be an underpinning mechanism to explain the depletion effect, however perceptions of boredom should be controlled for, particularly during the initial non-self-control task (Chapter Four).

Perceptions of Boredom

Recent literature has suggested that perceptions of boredom may be a potential underpinning mechanism explaining the effects of prior self-control exertion on subsequent physical performance (e.g., Wolff, Bieleke, Martarelli, & Danckert, 2021; Wolff & Martarelli, 2020), yet to our knowledge, this had not been empirically investigated previously. Findings from Chapter Four concluded that perceptions of boredom are not an underpinning mechanism to explain the effects of prior self-control exertion on subsequent physical performance. However, perceptions of boredom should be controlled for, particularly during the initial non-self-control task. This is because higher levels of boredom were observed when participants completed the non-self-control task (congruent Stroop task) compared to the self-control task (incongruent Stroop task) within Chapter Four. Findings are aligned with suggestions that control tasks frequently used within the self-control literature (e.g., congruent Stroop task) may increase boredom due to under-stimulation (Wolff, et al., 2021; Wolff & Martarelli, 2020).

It has therefore been suggested that increased perceptions of boredom during the non-self-control task may be responsible for the inconsistencies within the ego-depletion literature (Wolff & Martarelli, 2020; Wolff et al., 2021). This has implications for the design of future studies exploring the effects of prior self-control exertion on subsequent physical performance. Research has suggested that watching a neutral documentary may be a more suitable non-self-control task, as this engages participants but does not deplete their self-control (Mangin, André, Benraiss, Pageaux & Audiffren, 2021). For instance, in a series of experiments comparing a video task to a congruent Stroop task (which does not require self-control), researchers controlled for boredom, subjective fatigue, motivation, and affective state. Results revealed that the documentary task was not boring and did not induce fatigue, cause a reduction in motivation, or negatively impact affective state, whereas the congruent Stroop task (which does not require self-control) did influence fatigue, motivation, and affect. In addition, the neutral documentary condition resulted in greater depletion effects being observed (Mangin et al., 2021). Future research should consider that the choice of non-self-control tasks, within the sequential task paradigm, may have implications for the size of the depletion effect observed due to boredom in the control condition.

Self-efficacy

Chapter Two provides novel perspectives on the mechanisms that underpin the effects of prior self-control exertion on subsequent physical performance by analysing them under a meta-analytic lens for the first time. The findings revealed that the largest effect size was found for self-efficacy, whereby a statistically significant medium-sized negative effect was found (g = -0.48). This suggests that when self-control is exerted, individuals have a reduced belief that they possess the capabilities to mobilize the resources required to exert further self-control, which would be necessary to achieve optimal performance on a subsequent task (Bandura, 1977; Graham & Bray, 2015). Recognizing self-efficacy as a key mechanism has important implications for sport and exercise performance. Specifically, athletes and their support networks must be aware of the impact that initial acts of self-control exertion can have on the athlete's self-efficacy for a subsequent physical task. In accordance with *the shifting priorities model* and *opportunity-cost* conceptualization of self-control (Inzlicht & Schmeichel, 2016; Kurzban et al., 2013; Milyavskaya & Inzlicht, 2017), practitioners must realise that as athletes exert self-control, they may be less driven to exert further self-control if they do not feel confident that they can persevere at the physical task, and do not see any additional benefit in investing further self-control and effort. This will result in the cons of persisting at the task (i.e., increased feelings of discomfort) outweighing the benefits (i.e., optimal performance), and could lead to reduced physical performance and/or the termination of effort (Inzlicht, Shenhav & Olivola, 2018; Kool & Botvinick, 2014; Kurzban et al., 2013).

Motivation

Individuals' motivation has frequently been researched as a potential underpinning mechanism of self-control exertion on subsequent physical performance (e.g., Boat et al., 2018; Boat et al., 2020). Interestingly, Chapter Two revealed no effect of prior self-control exertion on motivation (g = -0.03). It was proposed that the findings were a result of motivation being measured at varied time-points in the included studies within the meta-analysis. For example, some research has measured motivation at pre-selected intervals throughout the physical performance task (e.g., Boat et al., 2018), while other studies have acquired a singular measurement of motivation prior to the physical task (e.g., Graham et al., 2018). To resolve these inconsistences, the current thesis aimed to investigate the time course of the changes in multiple facets of motivation (i.e., overall motivation, initial motivation, and task motivation) following the prior exertion of self-control. Chapter Three and Four both found support for motivation, whereby the prior exertion of self-control resulted in reduced motivation during the repeated running sprint task (Chapter Three) and wall-sit task (Chapter Four). Findings support previous research that has found reduced motivation during a physical performance task following the exertion of self-control (e.g., Boat et al., 2018; Boat et al., 2020), and are aligned with *the shifting priorities* and *opportunity-cost* conceptualization of self-control (Inzlicht & Schmeichel, 2016; Kurzban et al., 2013; Milyavskaya & Inzlicht, 2017). It is suggested that the initial exertion of self-control causes shifts in motivation (i.e., initial and overall), away from the distal goal (e.g., optimal physical performance) towards proximal temptations (reducing effort).

Acknowledging motivation as an underpinning mechanism for the effects of prior self-control exertion on subsequent physical performance has important implications for sport psychology practitioners. If an athlete is regularly required to self-regulate their behavior, the findings of this thesis suggests that this may have an impact on their motivation and subsequent performance. As such, strategies to refocus an individual's motivation, following self-control exertion, are required. One suitable strategy may be *situation selection,* whereby individuals actively chose situations that avoid temptations all together (Nielsen, Gwozdz, de

Ridder, 2019). For example, support staff could ensure that athletes are not placed in situations or routines that will place high demands on their self-control. As a result, this may reduce the likelihood of prior self-control exertion and thus motivation being influenced during subsequent physical performance (Werner & Milyavskaya, 2019). Future research could employ such motivation-based interventions to examine if motivation can be increased and attenuate the negative impact of prior self-control exertion on subsequent physical performance.

Perceptions of Pain

Individual's perceptions of overall pain and initial pain were also investigated throughout the current thesis. Chapter Two found no effect of prior self-control exertion on overall pain (g = 0.08) during a subsequent physical task, however, a small positive effect of initial perceptions of pain was demonstrated (g = 0.18). Findings are aligned with previous research suggesting that the prior exertion of self-control results in elevated perceptions of pain, but only during the early stages of a physical task (Boat & Taylor, 2017; Boat et al., 2020). Chapter Four revealed contradicting findings whereby differences in overall pain were observed, but no differences in initial pain (measured at 30 s into the wall-sit task) were demonstrated. Finally, Chapter Four and Five revealed no differences in participants' perceptions of pain during the wall-sit task (Chapter Four) and TTE cycling task (Chapter Five), however, this was attributed to the effects of self-control exertion potentially diminishing over time (Masicampo, Martin & Anderson, 2014; Steinborn & Huestegge, 2016; Tyler & Burns, 2008). Taken together, the results of the current thesis present inconsistent findings regarding the potential for perceptions of pain to be an underpinning mechanism to explain the effects of prior self-control exertion on subsequent physical performance. Chapters Two and Three provide some support for previous research that has reported an increase in perceptions of pain following self-control exertion (e.g., Boat & Taylor, 2017; Boat et al., 2020) and the attentional shifts proposed by *the shifting priorities* and *opportunity-cost* conceptualization of self-control (Inzlicht & Schmeichel, 2016; Kurzban et al., 2013; Milyavskaya & Inzlicht, 2017). However, the conflicting findings (Chapters Two and Three) and non-significant differences in perceptions of pain observed (Chapters Four and Five) suggest the need for future research to utilize, where possible, more objective measures of perceptions of pain.

Specifically, future research could employ the use of facial electromyography (EMG) to further investigate pain as an underpinning mechanism of self-control during physical performance (e.g., Bray, Martin Ginis, Hicks & Woodgate; Huang et al., 2014) EMG is a well-recognized method for measuring activity of skeletal muscles during physical activity (Blanchfield et al., 2014). In previous research, EMG activity of the facial muscles has successfully reflected the perception of effort and discomfort during high-intensity exercise (Huang et al., 2014). Therefore, this technique could be employed in future self-control research to objectively examine whether facial EMG activity reflects the perception of pain while engaging in physical tasks that require maximal effort, following the prior exertion of self-control (Boat et al., 2018).

Sustained Attention

Considering the suggestion that attention is a key mechanism underpinning self-control failure (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017); Chapter Two highlighted that there is limited research exploring attention as a mechanism that could potentially explain why the prior exertion of self-control negatively affects subsequent physical performance. Previous research has attempted to measure the effects of prior self-control exertion on attention regulation under pressure; however, in this study an additional manipulation of state anxiety was included, as such this study could not be included in the meta-analysis (Chapter Two) (Englert, Zwemmer, Bertrams & Oudejans, 2015), as it did not meet the eligibility criteria. Therefore, Chapter Three explored whether any performance decrements on a wall-sit task, following self-control exertion, could be explained by differences in sustained attention. Findings revealed no differences on a test of sustained attention (RVIPT) between the self-control exertion condition and non-self-control condition. These findings disagree with the tenants of *the shifting priorities model* of self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017) and previous research that has suggested that prior self-control exertion negatively affects sustained attention (Boat et al., 2021). Interestingly, given that participants in Chapter Four of this thesis completed the RVIPT ~10 minutes following the self-control task, it could be argued that the results support the notion that there is a washout period in which the detrimental effects of self-control are no longer present, and an individual’s self-control is replenished (Tyler & Burns, 2008). Future research could employ techniques such as tracking gaze behavior during a physical task (e.g., dart throwing task) to examine the time-course of self-control effects on sustained attention, and how this evolves over time. The exact point self-control “replenishes” could potentially be indicated by subsequential improvements in attention (assessed via eye-tracking) during a physical performance task (e.g., dart throwing task) (Englert et al., 2015).

Rating of Perceived Exertion (RPE)

Chapters, Two, Four, and Five of this thesis consistently demonstrated that RPE does not appear to be a mechanism that underpins the effects of prior self-control exertion on subsequent physical performance. Specifically, Chapter Two found limited evidence for the effects of self-control on RPE (g = 0.03). Chapter Four and Five aligned with this finding by failing to demonstrate a negative effect of prior self-control exertion on participants' RPE, whereby there was no difference in RPE during a wall-sit task (Chapter Four) and TTE cycling task (Chapter Five) between the self-control and non-self-control experimental conditions. Taken together, the findings support the argument that there appear to be key differences between self-control exertion and mental fatigue (e.g., Lee, Chatzisarantis, Hagger, 2016). While RPE has been considered as the main explanatory mechanism underpinning the effects of mental fatigue on subsequent physical performance (Pageaux & Lepers, 2018; Van Custem et al., 2017), the current thesis does not provide support for the role of RPE as an underpinning mechanism for the negative effects of self-control exertion on subsequent physical performance. It could be argued that self-control depletion tasks are not long enough to induce subjective feelings of effort (Pageaux, Marcora & Lepers, 2013) and therefore, self-control depletion tasks do not invoke the same mechanistic responses that underpin the effects of mental fatigue on subsequent physical performance (with mental fatigue tasks typically >30 min in duration, e.g., Brown et al., 2020). As a result, the current thesis recommends caution when combining self-control and mental fatigue research themes when conducting future mechanistic work, as performance decrements may not be attributed to the same mechanism. Future research could attempt to manipulate the duration of cognitive exertion tasks to induce both self-control depletion and mental fatigue, while assessing mechanisms such as RPE. This would allow for a direct comparison of the effects of self-control exertion and mental fatigue on subsequent physical performance, and the associated underpinning mechanisms.

Goal Priming Does Not Attenuate the Effects of Prior Self-Control Exertion on Subsequent Physical Performance

Given the need for interventions to attenuate or overcome the effects of self-control exertion on subsequent physical performance (Englert, 2019), Chapter Five of this thesis explored whether any performance decrements on a physical task, following the exertion of self-control, could be attenuated by goal priming. This hypothesis had only been tested in non-exercise settings previously (Walsh, 2014), whereby when participants were primed with different self-control goals (i.e., saving money and healthy eating), the negative impact of prior self-control exertion was attenuated during different measures of subsequent self-control ability (i.e., willingness to buy and actual food consumption). Chapter Five failed to replicate these findings in an exercise setting as goal priming did not improve endurance performance following the prior exertion of self-control. There are two possible explanations for these findings. First, prior self-control exertion did not affect TTE cycling task performance, despite confirmation that the manipulation of self-control was successful (via the CR10 scale and Stroop task performance). As a result it could be argued that there was no depletion effect to overcome. Further research is necessary to investigate the potential for prior self-control exertion to impair TTE cycling task performance. Moreover, it could be suggested that instructing participants to watch a video while cycling placed equivalent demand on self-control processes throughout each experimental condition. Therefore, future research could provide the goal prime before, or in preparation for, the performance task to reduce cognitive demand (Papies, 2016).

Alternatively, researchers could explore other interventions to attenuate the effects of prior self-control exertion on subsequent physical performance. One such intervention that aims to improve one's capacity to exert self-control is self-control training. The proposition behind self-control training is that by repeatedly overriding dominant responses, self-control strength will increase, and habitual behavior can be developed (Friese, Frankenbach, Job & Loschelder, 2017). In previous self-control training studies, participants are asked to complete everyday activities (e.g., brushing teeth, using the computer mouse) with their nondominant hand (e.g., Miles et al., 2016), refrain from using highly prevalent slang words (e.g., Finkel, DeWall, Slotter, Oaten, & Foshee, 2009), or to work on computerized tasks (e.g., modified Stroop task) requiring the control of dominant responses (e.g., Cranwell et al., 2014). In these studies, following a period of training (typically 2 weeks in duration), laboratory or everyday-life markers of self-control strength or stamina have been compared to a control group. Training effects have been seen in several domains including smoking cessation (Muraven, 2010), aggression reduction (Denson, Capper, Oaten, Friese, & Schofield, 2011) and the improvement of physical persistence (Cranwell et al., 2014).

Meta-analytical evidence provides support for the use of self-control training to improve self-control, demonstrating an overall small-to-medium positive effect on self-control performance (g = 0.30) (Friese et al., 2017). However, there have been debates regarding the effectiveness of self-control training. For example, following a six-week training programme of self-control tasks, trained participants did not improve at overcoming their habits, or report exerting more self-control in everyday life (Miles et al., 2016). Results infer that self-control training through repeated practice does not result in generalised improvements in self-control. Given the controversy regarding results, further research is necessary to develop sport-specific self-control training programs to examine their effectiveness in overcoming the negative impact of prior self-control exertion. Such work would have particular utility in those sporting tasks such as during a wall-sit task (Boat et al., 2020) and handgrip task (Graham, Li, Bray & Cairney, 2018) where self-control depletion has repeatedly and consistently been shown to impair subsequent physical performance.

Moreover, additional interventions such as providing motivational incentives (Brown & Bray, 2017a), biofeedback (Brown & Bray, 2019) and autonomy supportive instructions (Graham, Bray & Ginis, 2014) should be further investigated as potential methods to attenuate the self-control depletion effect. For instance, when participants were provided with heart rate biofeedback, following the depletion of self-control, participants performed at a similar exercise-intensity and work-rate during a cycling task to the non-self-control group (Brown & Bray, 2019). Findings highlight that biofeedback attenuates the negative effects of cognitive exertion, as such, further research is necessary to understand how biofeedback may interact with self-control processes in different physical performance tasks.

Strengths, Limitations, and Future Research Directions

The current thesis provides several findings which significantly advances the current self-control literature. A strength of this thesis is the theoretical bases upon which the proposed relationships were hypothesized. Recent investigations into the mechanisms underpinning physical performance decrements, following the exertion of self-control, has resulted in a movement away from the traditional strength model of self-control (Baumeister et al., 2007). The findings of this thesis add evidence that observed reductions in self-control over time may be a result of shifts in attentional and motivational foci. In particular, the findings of Chapter Three and Four are aligned with the tenants of *the shifting priorities model* of self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017). To illustrate, in Chapter Four, the exertion of self-control led to increased attention on the proximal tempting goal (i.e., perceptions of pain) and lower motivation to achieve optimal performance on the subsequent task (i.e., wall-sit task). Thus, participants' attentional and motivational foci was shifted towards the immediately gratifying tempting goal resulting in performance decrements. Although these findings appear to be consistent with *the shifting -*

priorities perspective (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), there are several avenues for further investigation.

For instance, the mechanistic findings of this thesis were all derived from self-report data. For example, motivation and perceptions of pain were measured using a self-report visual analogue scale (VAS) in Chapter Four. Previous research has suggested that mechanisms may not be shown to influence physical performance when assessed by self-report, and this could explain some of the null results observed (Stocker et al., 2020). As a result of this thesis, a movement towards more objective measures of potential mechanisms to further investigate the underpinning mechanisms of self-control exertion during physical performance is recommended. For example, electroencephalographic (EEG) data has shown that exerting self-control increases relative left frontal cortical activation, a section of the brain associated with motivation (Schmeichel, Crowell & Harmon-Jones, 2016). Although attentional and motivational processes have both previously been shown to mediate the effects of self-control exertion when assessed by a self-report visual analogue scale (VAS) (e.g., Boat & Taylor, 2017; Boat et al., 2018), future research should use more objective measures of mechanisms to examine the tenants of *the shifting priorities* perspective of self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017).

An additional strength of this thesis is the utilization of a controlled, counterbalanced, and within-subjects design with manipulation checks that were employed in Chapters Three, Four, and Five. A within-subjects design can remove problems related to between-subjects designs, including individual differences and homogeneity of groups (Hellier, 1998); it was also shown to reveal similar effect sizes to the between-group designs typically used in self-control research (see Chapter Two). Previous meta-analytical evidence has displayed larger effect sizes for studies that have utilized a between-subjects design (e.g., Brown et al., 2020). However, the present meta-analysis (Chapter Two) included more recent studies which could explain the discrepancies with previous findings. In light of these similar effect sizes, future studies should aim to continue employing within-subjects design over the more tradition between-subject designs to control for individual differences and increase the potential for replicability of the depletion effect (Boat et al., 2018).

Furthermore, the use of sport-specific performance tasks in Chapter Three and Five is perceived to be a strength of the current thesis. Employing whole-body endurance tasks such as a repeated running sprint task (Chapter Three) provided important findings regarding the type of physical tasks prior self-control exertion negatively impacts. As a result, these studies may be more generalizable to sport performance, compared to previous research that has utilized calisthenic measures of physical action (e.g., handgrip performance, wall-sit task performance; sit up and push up performance) (Wagstaff, 2014). However, it must be noted that all studies in the current thesis were completed in a laboratory-based environment, therefore, they may not be applicable to how prior self-control exertion impacts performance in a real-world competitive environment. Future studies should aim to conduct field study self-control research (e.g., Volleyball; Bieleke, Kriech & Wolff, 2019) to increase the ecological validity and generalizability of the research.

Chapters Three, Four, and Five of the current thesis utilized the Stroop task to empirically manipulate self-control. It is noteworthy to mention that the Stroop task is artificial in nature and not sport specific (Englert, 2016). The Stroop task has frequently been used in previous sport psychology research to manipulate self-control (e.g., Boat et al., 2020; Brown & Bray, 2019; Graham et al., 2018). In this current body of work, it was essential to use a well-established self-control task in a controlled setting (e.g., Boat & Taylor, 2017). However, future studies should aim to employ sport specific measures to deplete self-control to make conclusions drawn more applicable to sport psychology practitioners. Attempts have been made to use more sport specific self-control manipulation tasks (e.g., Englert & Betrams, 2014; Gröpel, Baumeister, & Beckmann, 2014). For example, participants were vicariously depleted via being asked to read stories about a soccer player who had to exert self-control throughout a competitive match. Following the story, participants were instructed to take the perspective of the described player. As participants envisaged themselves as the depleted athlete, they performed worse on a subsequent self-control task (Englert & Betrams, 2014). While these studies have attempted to create real world sporting conflicts that need to be resolved during the initial self-control manipulation task, the inclusion of more sport-related depletion tasks relevant to individual sports will create a more powerful argument for the importance of prior self-control exertion and subsequent physical performance in sports (Englert, 2016).

Similarly, Chapters Three, Four, and Five implemented the congruent and incongruent Stroop task for 4 min, however, recent research has suggested that engaging in longer durations of the initial Stroop task (i.e., the Stroop tasks in the current thesis) results in greater performance decrements on the subsequent physical task (Boat et al., 2020). While 4 min has frequently been shown as a sufficient period to successfully deplete self-control (e.g., Boat & Taylor, 2017; Boat et al., 2020; Boat, et al., 2021), it could be suggested that for more complex sporting physical tasks (i.e., tasks employed in Chapters Three and Five), longer durations of self-control exertion may be required to negatively influence subsequent physical performance. Future research could employ an initial self-control task for a longer duration to provide further understanding into the potential for the duration of the initial self-control task to impact subsequent complex sporting physical tasks (e.g., cycling task performance). Further investigation of the time course over which the effects of self-control exertion diminish, and how this interacts with the duration of the initial depletion task, could also provide useful insight.

Finally, it must be noted that the experimental studies (Chapters Three, Four and Five) included in this thesis included only recreationally active participants. Consequently, caution should be taken when generalizing findings to elite or well-trained athletes. Previous research has suggested that in well-trained populations, the continued pursuit of the same cognitive goal leads to the automatization of cognitive processes (Williams, Huang, & Bargh, 2009). When this occurs, self-control resources may not be required to the same degree as conscious self-control in novice performers (Schmeichel & Baumeister, 2004). Therefore, from a shifting priorities perspective (Inzlicht & Schmeichel, 2016), engaging in an initial task requiring self-control may not cause attentional and motivational foci to shift because conscious self-control is not required in well-trained performers (Baumeister & Bargh, 2014; Englert, 2019). However, findings may still be transferable to elite populations as, optimal endurance performance will still induce high levels of discomfort. Overcoming these demands may heighten the need for conscious self-regulation. As a result, even in well-trained populations, the initial exertion of self-control may lead to shifts in attention and motivation, because high levels of self-control will be necessary to persist on the task to optimize performance and resist the discomfort (Boat et al., 2017). Therefore, the undertaking of further mechanistic work, such as the current thesis, is necessary to determine whether prior self-control exertion leads to shifts in attentional and motivational focus in well-trained populations; and the implications of this for exercise performance.

Considering the proposed avenues for further investigation, the current thesis initiates a series of future hypotheses to investigate, including:

a) whether exerting self-control affects motivation and self-efficacy, and whether this may explain any subsequent reductions in physical performance;

b) whether shifts in motivation, following the prior exertion of self-control, are associated with increased stimulation at the prefrontal cortex;

c) whether a novel sport-specific self-control depletion task can deplete self-control to the same extent as the validated Stroop task, and negatively influence subsequent physical performance.

Summary

This thesis has offered evidence for the negative impact of prior self-control exertion on subsequent physical performance, as well as the potential for self-efficacy and motivation to be underpinning mechanisms to explain the effect. When all chapters of the current thesis are considered together, Chapter Two provides meta-analytical evidence that self-control exertion negatively impacts subsequent physical performance. However, these effects may be dependent on task type. Subsequently, Chapter Three, Four, and Five support this perspective as self-control depletion effects were seen for isometric physical tasks (i.e., wall-sit task) and not whole-body endurance tasks (i.e., repeated running sprint task and TTE cycling task). Self-control exertion is therefore suggested to affect the decision-making processes during physical performance. Whereby, isometric physical tasks (e.g., wall-sit task) may require more of an active decision whether to remain persistence during the task and therefore, may be more susceptible to the effects of prior self-control exertion than endurance-based physical tasks (e.g., cycling tasks). Moreover, aligned with the tenants of *the shifting priorities model* of self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), self-efficacy and motivation are proposed as suitable underpinning mechanisms to explain the effects of self-control exertion on subsequent physical task performance. Finally, Chapter Five provides evidence that goal priming does not attenuate the effects of prior self-control exertion on subsequent physical performance. The findings of the current thesis have thus contributed to the evidence base regarding the effects of prior self-control exertion on subsequent physical performance and the mechanisms by which these effects occur; thus, have implications for sport and exercise performance.

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Appendices

Appendix 1

PRISMA 2009 Checklist (Chapter Two)

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	27
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	28
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	29-33
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	29-33
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	N/A
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	33-34
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	34
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	34
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	35

Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	35
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	35
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	35
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	36
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	36

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	36, 48
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	37
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	34-35, Fig. 2.1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	35, Table 2.1
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	35, Fig. 2.2
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Fig. 2.3, Fig. 2.4a-b Fig. 2.5a-f
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	38-54, Fig. 2.3, Fig.

			2.4a-b, Fig. 2.5a-f
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	35
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	37
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	54-60
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	54-60
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	54-60
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	N/A

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.

Appendix 2

Sensitivity Analysis (Chapter Two)

Study Name	Hedge's g (95% CI) with study removed
Boat & Taylor, 2017	-0.53 [-0.67, -0.40]
Boat et al., 2018	-0.53 [-0.67, -0.40]
Alberts et al., 2007 (study 2)	-0.55 [-0.70, -0.40]
Boat et al., 2020	-0.55 [-0.71, -0.40]
Englert, Persaud, Oudejans & Bertrams, 2015	-0.55 [-0.71, -0.40]
Graham et al., 2017	-0.55 [-0.71, -0.40]
Graham et al., 2018	-0.55 [-0.71, -0.40]
Alberts et al., 2007 (study 1)	-0.56 [-0.71, -0.40]
Brown & Bray, 2017	-0.56 [-0.71, -0.40]
Graham et al., 2014	-0.56 [-0.71, -0.40]
Ciarocco et al., 2001	-0.56 [-0.71, -0.41]
Englert, Bertrams, Furley & Oudejans, 2015	-0.56 [-0.71, -0.41]
Shaabani et al., 2020	-0.56 [-0.71, -0.41]
Tyler & Burns, 2008 (study 1)	-0.56 [-0.71, -0.41]
Brown & Bray, 2019	-0.56 [-0.72, -0.40]
Bray et al., 2011	-0.56 [-0.72, -0.41]
Finkel et al., 2006	-0.56 [-0.72, -0.41]
Graham et al., 2015	-0.56 [-0.72, -0.41]
Martijn et al., 2002	-0.56 [-0.72, -0.41]
Martijn et al., 2007	-0.56 [-0.72, -0.41]
Boat et al., 2020	-0.57 [-0.72, -0.41]
Boat et al., 2020	-0.57 [-0.72, -0.41]
Bray et al., 2008	-0.57 [-0.72, -0.41]

Bray et al., 2013	-0.57 [-0.72, -0.41]
Brown et al., 2017	-0.57 [-0.72, -0.41]
Brown et al., 2017	-0.57 [-0.72, -0.41]
Brown et al., 2017	-0.57 [-0.72, -0.41]
Dorris et al., 2015 (study 1)	-0.57 [-0.72, -0.41]
Englert & Bertrams, 2014	-0.57 [-0.72, -0.41]
Enlgert & Wolff, 2015	-0.57 [-0.72, -0.41]
Wagstaff, 2014	-0.57 [-0.72, -0.41]
Stocker et al., 2020	-0.57 [-0.72, -0.41]
Yusainy & Lawrence, 2015	-0.57 [-0.73, -0.41]
Boat et al., 2017	-0.57 [-0.73, -0.42]
Boat et al., 2021	-0.57 [-0.73, -0.42]
Brown et al., 2017	-0.57 [-0.73, -0.42]
Dorris et al., 2015 (study 2)	-0.57 [-0.73, -0.42]
Englert et al., 2012 (study 1)	-0.57 [-0.73, -0.42]
Englert et al., 2012 (study 2)	-0.57 [-0.73, -0.42]
Graham et al., 2012	-0.57 [-0.73, -0.42]
Martin Ginis et al., 2010	-0.57 [-0.73, -0.42]
Muraven et al., 1998	-0.57 [-0.73, -0.42]
Schücker et al., 2016 (study 1)	-0.57 [-0.73, -0.42]
Zering et al., 2017	-0.57 [-0.73, -0.42]
Brown et al., 2017	-0.58 [-0.73, -0.42]
McEwan et al., 2013	-0.58 [-0.73, -0.42]
Murtagh et al., 2004	-0.58 [-0.73, -0.42]
O'Brien et al., 2020	-0.58 [-0.73, -0.42]
Schücker et al., 2016 (study 2)	-0.58 [-0.73, -0.42]
Xu et al., 2014	-0.59 [-0.74, -0.44]

Appendix 3

Health screen Questionnaire (Chapter Three, Four & Five)

Name or Number ……………………………

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:

(a)	on medication, prescribed or otherwise	Yes ☐	No ☐
(b)	attending your general practitioner	Yes ☐	No ☐
(c)	on a hospital waiting list	Yes ☐	No ☐

2. **In the past two years,** have you had any illness which require you to:

(a)	consult your GP	Yes ☐	No ☐
(b)	attend a hospital outpatient department	Yes ☐	No ☐
(c)	be admitted to hospital	Yes ☐	No ☐

3. **Have you ever** had any of the following?

(a)	Convulsions/epilepsy	Yes ☐	No ☐
(b)	Asthma	Yes ☐	No ☐
(c)	Eczema	Yes ☐	No ☐
(d)	Diabetes	Yes ☐	No ☐
(e)	A blood disorder	Yes ☐	No ☐
(f)	Head injury	Yes ☐	No ☐
(g)	Digestive problems	Yes ☐	No ☐
(h)	Heart problems	Yes ☐	No ☐
(i)	Problems with bones or joints	Yes ☐	No ☐
(j)	Disturbance of balance / coordination	Yes ☐	No ☐
(k)	Numbness in hands or feet	Yes ☐	No ☐
(l)	Disturbance of vision	Yes ☐	No ☐

(m)	Ear / hearing problems	Yes ☐	No ☐
(n)	Thyroid problems	Yes ☐	No ☐
(o)	Kidney or liver problems	Yes ☐	No ☐
(p)	Allergy to nuts, alcohol etc.	Yes ☐	No ☐
(q)	Any problems affecting your nose e.g. recurrent nose bleeds	Yes ☐	No ☐
(r)	Any nasal fracture or deviated nasal septum	Yes ☐	No ☐
4.	**Has any,** otherwise healthy, member of your family under the age of 50 died suddenly during or soon after exercise?	Yes ☐	No ☐
5.	Are there any reasons why blood sampling may be difficult?	Yes ☐	No ☐
6.	Have you had a blood sample taken previously?	Yes ☐	No ☐
7.	Have you had a cold, flu or any flu like symptoms in the last	Yes ☐	No ☐ Month?

Appendix 4

Participant Statement of Consent (Chapter Three)

"Examining the relationship between cognitive effort on repeated running sprint exercise"

- I, ____________________ agree to partake as a participant in the above study.

- I understand from the participant information sheet, which I have read in full, and from my discussion with Raymon Hunte that this will involve me attending the lab on 3 occasions for a total of 3 hours. During the main trials, I will complete cognitive tests and a repeated sprint exercise task.

- It has also been explained to me by Raymon Hunte that the risks and side effects that may result from my participation are as follows: injury or nausea from maximal exercise.

- I confirm that I have had the opportunity to ask questions about the study and, where I have asked questions, these have been answered to my satisfaction.

- I undertake to abide by University regulations and the advice of researchers regarding safety.

- I am aware that I can withdraw my consent to participate in the procedure at any time and for any reason, without having to explain my withdrawal and that my personal data will be destroyed and that my medical care or legal rights will not be affected.

- I understand that any personal information regarding me, gained through my participation in this study, will be treated as confidential and only handled by individuals relevant to the performance of the study and the storing of information thereafter. Where information concerning myself appears within published material, my identity will be kept anonymous.

- I confirm that I have had the University's policy relating to the storage and subsequent destruction of sensitive information explained to me. I understand that sensitive information I have provided through my participation in this study, in the form of blood samples, physiological responses, and measurements will be handled in accordance with this policy.

- I confirm that I have completed the health questionnaire and know of no reason, medical or otherwise that would prevent me from partaking in this research.

- It has been explained to me that there may be additional risks arising from the current COVID pandemic. I have read the NTU recommendations for undertaking 'Research with human participants' and undertake to abide by the special measures which have been explained to me for this study together with such Government Guidelines that are at the time prevailing.

Participant signature: Date:
Independent witness signature: Date:
Primary Researcher signature: Date:

Appendix 5

Participant Information Sheet (Chapter Three)

"Examining the relationship between cognitive effort and repeated running sprint exercise"

- **Brief Introduction:**

Recent research has demonstrated that following a cognitive task that requires mental effort, individuals perform worse at a physically demanding task. However, the effect of such tasks on repeated sprint running performance has not been assessed.

- **Study Requirements:**

You will be required to attend 3 testing sessions in total. On one occasion you will complete a familiarisation trial, during this trial you will be instructed on how to complete the repeated sprint exercise task and given an opportunity to practice the other tests involved in the study. Next, on two separate occasions, you will be asked to perform the repeated sprint exercise task once immediately following a cognitively demanding task and once immediately following a cognitively simple task. Both cognitive tasks will have a 4-minute duration. Furthermore, blood lactate concentration will be measured at rest, immediately post the repeated sprint exercise task, and 5 mins post the repeated sprint exercise task, using a capillary blood sample. All trials will be separated by at least 24hr week.

- **Location:**

Data collection will take place in the Sport Science Laboratories (ERD 140, 145, 249, ISC034) at Nottingham Trent University (Clifton Campus).

- **General Requirements:**

You must be physically active, and a non-smoker aged 18-39 years.

- **Restrictions During Testing:**
- You will be required to record your diet for one day prior to the first main trial and repeat this prior to the second trial.
- You should not consume any food during the 2 hours prior to each main trial.
- You should not engage in any demanding exercise or physical activity during the 24 hours before each main trial.
- You will be required to refrain from alcohol consumption during the 48 hours before each main trial.
- You will be required to refrain from caffeine consumption during the 24 hours before each main trial.

- **Testing Protocol:**

You will complete a repeated sprint exercise task on a nonmotorized treadmill. This will include performing 5 x 6 second maximal sprints, interspersed with 24 seconds passive recovery. Prior to completing the repeated sprint exercise task, you will complete a cognitively demanding task (hard Stroop task) or a cognitively simple task (easy Stroop task), each lasting 4 minutes. Blood lactate concentrations will be measured at rest, immediately post the repeated sprint exercise task, and 5 mins post the repeated sprint exercise task, using a capillary blood sample. You will be required to complete 3 testing sessions in total. Each session will last approximately 1 hour.

- **<u>Potential Benefits to You:</u>**

If you wish, a report that will summarize your performance in the repeated sprint exercise task in the context of the study will be provided.

- **<u>Potential Risks to You:</u>**

As you will be aware, there is always a danger with maximal type exercise. Specific risks are outlined below.

- Finger prick blood sampling can result in minor bruising, but this is short-lived.
- Repeated sprinting may result in a muscle strain. However, as an active individual you will be familiar with this type of exercise, therefore limiting the chance of this occurring.
- Repeated sprinting is maximal exercise and therefore will lead to physical exhaustion, but you should recover within a few minutes. In a tiny minority of individuals, even in young adults, the possibility exists that such exercise triggers disturbances to normal physiology: these include abnormal blood pressure, fainting or a change in the normal rhythm of the heart. Although it is extremely unlikely, high intensity exercise has been known to reveal unsuspected heart or circulation problems and very rarely these have had serious or fatal consequences.

If at any point you decide to withdraw from the study your data will be destroyed.

- **<u>Contacts:</u>**

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Appendix 6

Daily Inventory of Stressful Events Questionnaire
(Chapter Three, Four & Five)

Please indicate whether any of the following events have occurred today by circling the correct response:

An argument or disagreement with someone	Yes	No
Anything else that you could have argued about but decided to let it pass in order to avoid a disagreement	Yes	No
Anything at work or university that most people would consider stressful	Yes	No
Anything at home that most people would consider stressful	Yes	No
Discrimination on the basis of such things as sexual orientation, race sex, or age	Yes	No
Anything happen to a close friend or relative that turned out to be stressful	Yes	No
Anything else that most people would consider stressful	Yes	No

Appendix 7

Fatigue Questionnaire (Chapter Three & Five)

Please rate how you feel at this moment in time, i.e., **right now**

	Not at all true		Somewhat true		Very true
I feel physically worn out	1	2	3	4	5
I feel physically exhausted	1	2	3	4	5

Appendix 8

Mental Exertion Questionnaire (Chapter Three, Four & Five)

Please rate your mental exertion in the cognitive task. Please circle your answer.

0	Nothing at all
0.5	Extremely Weak (Just Noticeable)
1	Very Weak
2	Weak (Light)
3	Moderate
4	
5	Strong (Heavy)
6	
7	Very Strong
8	
9	
10	Extremely Strong (Almost Max)

Appendix 9

1–20-point Perception Scales (Chapter Three)
1–20-point scale for motivation

Participant's ID:__________

Please rate how motivated you are for the next upcoming sprint, from 1 *(I Have Zero Motivation To Continue With The Task)* to 20 *(I Am Fully Motivated To Continue With The Task)*:

1	***I HAVE ZERO MOTIVATION TO CONTINUE WITH THIS TASK***
2	
3	
4	
5	**LITTLE MOTIVATION**
6	
7	
8	
9	
10	**SOMEWHAT MOTIVATED**
11	
12	
13	
14	
15	**VERY MOTIVATED**
16	
17	
18	
19	
20	***I AM FULLY MOTIVATED TO CONTINUTE WITH THIS TASK***

1–20-point scale for pain (Chapter Three)

Participant’s ID:__________

Please rate your current level of pain experienced during this sprint *(No Pain)* to 20 *(Worst Possible Pain)*:

1	***NO PAIN***
2	
3	
4	
5	**LITTLE PAIN**
6	
7	
8	
9	
10	**SOMEWHAT PAINFUL**
11	
12	
13	
14	
15	**VERY PAINFUL**
16	
17	
18	
19	
20	***WORST POSSIBLE PAIN***

1–20-point scale for RPE (Chapter Three)

Participant’s ID:__________

Please rate your current rating of perceived exertion (RPE) experienced during this sprint *(No Exertion/Rest)* to 20 *(Maximum Exertion)*:

1	***NO EXERTION***
2	
3	
4	
5	**EASY**
6	
7	
8	
9	
10	**SOMEWHAT HARD**
11	
12	
13	
14	
15	**VERY HARD**
16	
17	
18	
19	
20	***MAXIMAL EXERTION***

Appendix 10

<u>Participant Statement of Consent (Chapter Four)</u>

"Examining the relationship between cognitive effort and perceptions of exercise-related pain."

1) I, (participant name) ………………………………………………………… agree to partake as a participant in the above procedure.

2) I understand from the participant information sheet, which I have read in full, and from my discussion(s) with Raymon Hunte that this will involve me performing a standing wall-sit for as long as possible until voluntary exhaustion. During this wall-sit, I will be instructed to record my perceptions of exercise related pain. This procedure will be performed on 2 occasions. On one occasion, I will complete a cognitively demanding task immediately prior to performing the wall-sit task. On another occasion, I will complete a cognitively simple task immediately prior to performing the wall-sit task. Each testing session will last approximately 45 minutes.

3) It has also been explained to me by Raymon Hunte that the risks and side effects which may result from my participation are as follows: I may slightly ache afterwards from completing the standing wall-sit.

4) I confirm that I have had the opportunity to ask questions about the study and, where I have asked questions, these have been answered to my satisfaction.

5) I undertake to abide by University regulations and the advice of researchers regarding safety.

6) I am aware that I can withdraw my consent to participate in the procedure at any time and for any reason, without having to explain my withdrawal and that my personal data will be destroyed.

7) I understand that any personal information regarding me, gained through my participation in this study, will be treated as confidential and only handled by individuals relevant to the performance of the study and the storing of information thereafter. Where information concerning myself appears within published material, my identity will be kept anonymous.

8) I confirm that I have had the University's policy relating to the storage and subsequent destruction of sensitive information explained to me. I understand that sensitive information I have provided through my participation in this procedure, in the form of questionnaires will be handled in accordance with this policy.

9) I confirm that I have completed the health questionnaire and know of no reason, medical or otherwise that would prevent me from partaking in this research.

Participant signature:	Date:
Independent witness signature:	Date:
Primary Researcher signature:	Date:

Appendix 11
Participant Information Sheet (Chapter Four)

“Examining the relationship between cognitive effort and perceptions of exercise-related pain.”

Brief Introduction:

Recent research has demonstrated that following a task that requires mental effort, individuals perform worse at a physically demanding task, such as a wall-sit task. Evidence also suggests that following a task that requires mental effort, individuals may experience higher perceptions of pain during the physically demanding task (e.g., wall-sit task), as well as a change in motivation towards the physical task.

Study Requirements:

On two separate occasions, you will be asked to perform a standing wall-sit for as long as possible. During this physical task, you will be instructed to record your perceptions of exercise related pain. Immediately prior to performing the standing wall-sit, you will complete a cognitively demanding task or a cognitively simple task.

Location:

Sport Psychology Laboratory, Nottingham Trent University, Clifton Campus

Restrictions During Testing:

You are required to avoid strenuous exercise in the 48 hours prior to testing and avoid all exercise on test days. Alcohol and caffeine are prohibited on test days. You are required to arrive at the laboratory 3 hours after your previous meal (you are free to consume water in this period).

Testing Protocol:

You will complete a standing wall-sit for as long as possible. The standing wall-sit requires you to stand with your back directly against a wall, feet shoulder width apart and knees and hips flexed at a 90° angle, with your hands resting against the wall. Whilst completing the wall-sit task, you will complete the Visual Analog Scale for pain. This is a 10cm line, where one end represents no pain and the other end represents the worst pain. You will be asked to make a mark on the line that represents your current pain perceptions. You will be instructed to complete the Visual Analog Scale for pain at 20-second intervals for the entire duration of the wall-sit task.

These procedures will be performed on 2 occasions. On one occasion, you will complete a cognitively demanding task for 5-minutes immediately prior to the wall-sit task. On another occasion, you will complete a cognitively simple task for 5-minutes immediately prior to the wall-sit task.

In the cognitive tasks, you will be presented with lists of coloured words and will be required to read aloud the colour of the print ink and ignore the text for each word presented.

Each testing session will last approximately 45 minutes.

Potential Benefits to You:

Experience as a participant in a sports science research trial (particular benefit to sport science students).

Potential Risks to You:

No adverse effects are anticipated from performing the cognitive task or standing wall-sit. You may slightly ache afterwards from completing the standing wall-sit. You may also experience some slight delayed onset of muscle soreness in the 48 hours following your testing session, but this discomfort will be temporary and will have no lasting consequences. Although it is extremely unlikely, high intensity exercise has been known to reveal unsuspected heart or circulation problems and very rarely these have had serious or fatal consequences. If at any point you decide to withdraw from the study your data will be destroyed.

Due to the current pandemic in the UK (and around the World), interactions between people from different households carries a risk of COVID-19 infection. The researcher will always wear PPE (personal protective equipment – specifically a surgical mask). The researcher will mitigate the risk of infection by maintaining a two-metre distance other than when certain measurements are being made. When these certain measurements are made, the researcher will always stand to the side of you. All facilities in which research is being conducted have been COVID19 risk assessed.

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Appendix 12

Academic Boredom Scales **(Chapter Four)**

ABS-10 *(after Stroop)*

Thinking about the Stroop task that you have just completed, to what extent did you:

	Extremely								Not at all
Have nothing to do or think about	1	2	3	4	5	6	7	8	9
Find the activity dull	1	2	3	4	5	6	7	8	9
Feel it was repetitive	1	2	3	4	5	6	7	8	9
Wonder why you were doing it	1	2	3	4	5	6	7	8	9
Feel it was useless and unimportant, that you were wasting your time	1	2	3	4	5	6	7	8	9
Want to do something else	1	2	3	4	5	6	7	8	9
Get tired of the activity	1	2	3	4	5	6	7	8	9
Become impatient	1	2	3	4	5	6	7	8	9
Become frustrated or annoyed	1	2	3	4	5	6	7	8	9
Feel apathetic, not wanting to do anything	1	2	3	4	5	6	7	8	9

<u>ABS-10</u> *(after wall-sit task)*
(Chapter Four)

Thinking about the <u>Wall-Sit</u> task that you have just completed, to what extent did you:

	Extremely								Not at all
Have nothing to do or think about	1	2	3	4	5	6	7	8	9
Find the activity dull	1	2	3	4	5	6	7	8	9
Feel it was repetitive	1	2	3	4	5	6	7	8	9
Wonder why you were doing it	1	2	3	4	5	6	7	8	9
Feel it was useless and unimportant, that you were wasting your time	1	2	3	4	5	6	7	8	9
Want to do something else	1	2	3	4	5	6	7	8	9
Get tired of the activity	1	2	3	4	5	6	7	8	9
Become impatient	1	2	3	4	5	6	7	8	9
Become frustrated or annoyed	1	2	3	4	5	6	7	8	9
Feel apathetic, not wanting to do anything	1	2	3	4	5	6	7	8	9

Appendix 13

Visual Analog Scale (Chapter Four)

<u>Visual Analog Scale for Pain</u>

Please rate the pain you are feeling right now.

No Pain

Worse Possible Pain

<u>Visual Analog Scale for Motivation</u>

Please rate your motivation right now.

I Have Zero Motivation To Continue With The Wall-Sit Task

I Am Fully Motivated To Continue With The Wall-Sit Task

Appendix 14

<u>Participant Statement of Consent (Chapter Five)</u>

Examining the effects of mental exertion on performance during an endurance cycling task.

1) I, _______________________________*(participant name)* agree to partake as a participant in the above study.

2) I understand from the participant information sheet (Dated…… Version…….), which I have read in full, and from my discussion(s) with *Raymon Hunte* that this will involve me performing a preliminary fitness test on my first visit to the lab. Following this, I will complete a time to exhaustion (TTE) cycling trial for as long as possible. During this trial, I will be instructed to complete a visual task and record my perceptions of exercise related pain, motivation, and effort. This procedure will be performed on 3 occasions. During these trials, I will complete a simple cognitive task requiring very little mental effort or a demanding cognitive task requiring mental effort, for a duration of 4 minutes. Each testing session will last approximately 60 minutes.

3) It has also been explained to me by Raymon Hunte that the risks and side effects that may result from my participation are as follows: I may slightly ache afterwards from completing the cycling task.

4) I confirm that I have had the opportunity to ask questions about the study and, where I have asked questions, these have been answered to my satisfaction.

5) I undertake to abide by University regulations and the advice of researchers regarding safety.

6) I am aware that I can withdraw my consent to participate in the procedure at any time and for any reason, without having to explain my withdrawal and that my personal data will be destroyed and that my medical care or legal rights will not be affected.

7) I understand that any personal information regarding me, gained through my participation in this study, will be treated as confidential and only handled by individuals relevant to the performance of the study and the storing of information thereafter. Where information concerning myself appears within published material, my identity will be kept pseudo-anonymised.

8) I confirm that I have had the University's policy relating to the storage and subsequent destruction of sensitive information explained to me. I understand that sensitive information I have provided through my participation in this study, in the form of questionnaires will be handled in accordance with this policy.

9) I confirm that I have completed the health questionnaire and know of no reason, medical or otherwise that would prevent me from partaking in this research.

10) I confirm that I understand the COVID-19 precautions that will be implemented in this study and that I have had the opportunity to ask questions about these precautions. Where we have asked questions, these have been answered to our satisfaction.

Participant signature:	Date:
Independent witness signature:	Date:
Primary Researcher signature:	Date:

Appendix 15

Participant Information Sheet (Chapter Five)

"Examining the effects of mental exertion on performance during an endurance cycling task."

- Brief Introduction:

Recent research has demonstrated that following an initial task that requires mental effort, individuals perform worse at a subsequent endurance-based task, such as cycling. However, the mechanisms underpinning these decrements in performance following mental exertion are relatively unknown.

- Study Requirements:

You will be required to visit the laboratory on four separate occasions. The first visit to the lab will require you to complete a preliminary fitness test. During this test, VO2 Max measurements will be taken – this is considered the gold standard or most accurate test of aerobic or cardiovascular fitness. For the remaining visits, you will be asked to complete a time to exhaustion (TTE) cycling trial. During this physical task, you will participate in a visual task delivered via a laptop. Immediately prior to performing the cycling trial, you will complete a simple cognitive task (which requires very little mental effort) or a demanding cognitive task (which requires mental effort) for a duration of 4 minutes.
Location:
Sport Psychology Laboratory (ERD Lab 249), Nottingham Trent University, Erasmus Darwin Building, Clifton Campus.

- Restrictions During Testing:

You are required to avoid strenuous exercise in the 48 hours prior to testing and avoid all exercise on test days. Alcohol and caffeine are prohibited on test days. You are required to arrive at the laboratory 3 hours after your previous meal (you are free to consume water in this period).

- Testing Protocol:

You will be asked to complete a demanding or simple cognitive task. In the cognitive tasks, a word (always a colour) will appear in the centre of the computer screen, and you must choose the colour of the ink and ignore the text of each word presented, using response pad. Following this, you will be required to complete a time to exhaustion (TTE) cycling trial on a cycle ergometer. During the trial you will be required to complete a 'Scanning Visual Vigilance Task'. This will involve looking out for a coloured circle that will appear in a random location on the laptop screen. No response is required; however, you will be required to pay close attention to the circle. In addition, at various intervals you will be asked to answer aloud a set of questions surrounding your perceptions of pain, motivation, and perceived effort. Your heart rate will be monitored throughout the trial. Following the exercise process there will be an opportunity to complete a cool down. The testing session will last approximately 60 minutes.

- Potential Benefits to You:

If you wish, a report that will summarize your performance in the time-trials in the context of the study will be provided.
Experience as a participant in a sports science research trial (particular benefit to sport science students).

- Potential Risks to You:

No adverse effects are anticipated from performing the cognitive task or cycling time trial. You may slightly ache afterwards from completing the cycling time trial. You may also experience some slight delayed onset of muscle soreness in the 48 hours following your testing session, but this discomfort will be temporary and will have no lasting consequences. Although it is extremely unlikely, high intensity exercise has been known to reveal unsuspected heart or circulation problems and very rarely these have had serious or fatal consequences. You can withdraw your consent to participate in the study at any time and for any reason, without having to explain your withdrawal and your personal data will be destroyed.

Due to the current pandemic in the UK (and around the World), interactions between people from different households carries a risk of COVID-19 infection. The researcher will always wear PPE (personal protective equipment – specifically a surgical mask). The researcher will mitigate the risk of infection by maintaining a two-metre distance other than when certain measurements are being made. When these certain measurements are made, the researcher will always stand to the side of you. All facilities in which research is being conducted have been COVID19 risk assessed.

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Appendix 16

Food and Activity Diary (Chapter Five)

Participant code: Date:

Lab Visit:

	Time	Meal	Portion	Fluid Intake	Activity
Breakfast					
Lunch					
Dinner					
Snacks					

Appendix 17

1–20-point perception scales (Chapter Five)

1–20-point scale for motivation

Participant's ID:__________

Please rate how motivated you are to continue exerting the effort required to rotate the pedals, from 1 *(I Have Zero Motivation To Continue With The Task)* to 20 *(I Am Fully Motivated To Continue With The Task)*:

1	***I HAVE ZERO MOTIVATION TO CONTINUE WITH THIS TASK***
2	
3	
4	
5	**LITTLE MOTIVATION**
6	
7	
8	
9	
10	**SOMEWHAT MOTIVATED**
11	
12	
13	
14	
15	**VERY MOTIVATED**
16	
17	
18	
19	
20	***I AM FULLY MOTIVATED TO CONTINUTE WITH THIS TASK***

1–20-point scale for task importance (Chapter Five)

Participant’s ID:__________

Please rate the importance of completing the time to exhaustion (TTE) trial as quickly as possible *(not important at all)* to 20 *(extremely important)*:

1	***NOT IMPORTANT AT ALL***
2	
3	
4	
5	**LITTLE IMPORTANCE**
6	
7	
8	
9	
10	**SOMEWHAT IMPORTANT**
11	
12	
13	
14	
15	**VERY IMPORTANT**
16	
17	
18	
19	
20	***EXTREMELY IMPORTANT***

1–20-point scale for pain (Chapter Five)

Participant's ID:__________

Please rate your current level of pain experienced during this trial *(No Pain)* to 20 *(Worst Possible Pain)*:

1	***NO PAIN***
2	
3	
4	
5	**LITTLE PAIN**
6	
7	
8	
9	
10	**SOMEWHAT PAINFUL**
11	
12	
13	
14	
15	**VERY PAINFUL**
16	
17	
18	
19	
20	***WORST POSSIBLE PAIN***

1–20-point scale for RPE (Chapter Five)

Participant's ID:__________

Please rate your current rating of perceived exertion (RPE) experienced during this trial *(No Exertion/Rest)* to 20 *(Maximum Exertion)*:

1	***NO EXERTION***
2	
3	
4	
5	**EASY**
6	
7	
8	
9	
10	**SOMEWHAT HARD**
11	
12	
13	
14	
15	**VERY HARD**
16	
17	
18	
19	
20	***MAXIMAL EXERTION***

Appendix 18

Study Feedback Questionnaire (Chapter Five)

Please read each question carefully and tick a box to indicate your answer:

During the video, do you recall seeing any words related to performance?

YES ❑

NO ❑