EFFECTS OF SELF-CONTROL EXERTION ON MENTAL FATIGUE AND PERCEIVED EXERTION DURING WHOLE-BODY EXERCISE

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ABSTRACT

Self-control exertion leads to performance decrements during tasks demanding of muscular and cardiovascular systems (Bray et al., 2008; Marcora et al., 2009). Several reviews have also implicated self-control depletion with the psychobiological state of fatigue (Hagger et al., 2010; Van Cutsem et al., 2017). In this state, individuals have also been noted to report higher levels of perceived exertion when exercising at vigorous intensities (MacMahon et al., 2014; Marcora et al., 2009; Wagstaff et al., 2014). The purpose of this study was to investigate physical performance and ratings of perceived exertion during a self-paced maximum distance cycling trial (MDT) following a short bout of mentally-fatiguing cognitive activity (thought-suppression). Recreationally active participants ($N = 16$, $M_{age} = 20.94$) completed one familiarization session and two testing sessions. All visits were separated by ≥ 72-hours. Control and experimental trials were counterbalanced, with either a 6-minute bout of thought-logging (control) or a 6-minute bout of thought-suppression (experimental) being performed prior to each respective MDT. Ratings of perceived exertion (RPE) were solicited from participants across three sensory domains relevant to MDT task performance (Leg-muscle, Respiration, Mental). Thought-suppression was perceived to be significantly more demanding than the control task, which resulted in significantly higher ratings of mental fatigue ($p = 0.04$, $\eta^2 = 0.26$). Distance travelled on the MDT was not significantly different following thought suppression, relative to control trials ($p = 0.84$, $\eta^2 = 0.00$). Similarly, a repeated-measures ANOVA showed no differences in HR between conditions ($p = 0.95$, $\eta^2 = 0.00$). Despite these similarities, ratings of perceived leg-muscle exertion (RPE-L) were significantly higher during the MDT following thought-suppression ($p = 0.05$, $\eta^2 = 0.24$). RPE-R (respiration) and RPE-M (mental) ratings also trended towards higher scores following the experimental manipulation, although they did not differ significantly. RPE-L was perceived to be significantly higher than both RPE-R and RPE-M in both conditions on the MDT (*ps* < 0.05). RPE-M was rated significantly lower than RPE-L and RPE-R during MDTs in both conditions (*ps* < 0.05). Results indicate that performing a demanding self-control exertion task for a short duration leads to increased feelings of mental fatigue. The observed levels of fatigue were also associated with higher than normal ratings of perceived exertion during cycling tasks of equal demands and performance.

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LIST OF ABBREVIATIONS

ACC	Anterior Cingulate Cortex
ANOVA	Analysis of Variance
AX-CPT	AX-Continuous Performance Task
CMJ	Countermovement Jump
dRPE	Differential Ratings of Perceived Exertion
GXT	Graded Exercise Task
HG	Handgrip
HR	Heart Rate
MDT	Maximum Distance Trial
NASA TLX	NASA Task Load Index
RPE	Ratings of Perceived Exertion
RPE-L	Ratings of Perceived Exertion – Leg Muscle
RPE-M	Ratings of Perceived Exertion – Mental
RPE-R	Ratings of Perceived Exertion – Respiration
RPM	Rotations per Minute
SST	Stop-Signal Task
TT	Time Trial
TTE	Time-to-exhaustion

DECLARATION OF ACADEMIC ACHIEVEMENT

Jason Langvee's role:

- Amended ethics application at McMaster University
- Designed study protocol and chose measures
- Recruited participants
- Organized visits and set up lab equipment and materials
- Supervised volunteers assisting with data collection
- Performed the data analysis
- Wrote the manuscript

Role of co-authors:

- SB assisted JL with ethics application
- SB assisted JL with study design and selection of measures
- SB obtained study funding
- SB assisted JL with data analysis and interpretation
- SB provided feedback and minor revisions on the manuscript

Introduction

Self-regulation or self-control refers to any effort undertaken by an individual to alter his/her own actions or responses that include actions, thoughts, feelings, desires, and performance (Baumeister, Heatherton, & Tice, 1994). Self-control is essential in domains including education (de Ridder, Lensvelt-Mulders, Finknauer, Stok & Baumeister, 2012), employment/job performance (Bechtoldt, Welk, Zapf & Hartig, 2007), physical exercise (Englert, 2016) and sport (Kirschenbaum, 1987). With regards to exercise, people use self-control to persevere throughout exhausting workouts in order to reap the full benefits of the bout. Exerting self-control during exercise can involve overriding feelings of discomfort that accompany high levels of exertion. The same can be said in the world of sport, where athletes push themselves to the extreme of their physical and mental limits to pursue their goals.

However, as most people who exercise can attest, not every workout feels the same and even experienced exercisers who have established routines know that exercise feels harder on some days relative to others. A question arises then as to what factors change how effortful exercise feels and whether self-control is a factor that not only influences what we do (or don't do); but also, how we feel when we are doing it.

One theoretical perspective that has been used extensively by researchers in the investigation of self-control and its impact on behavioural regulation is the strength model of self-control (Baumeister & Vohs, 2016). The strength model stipulates that self-control is governed by a brain-based resource that can be exhausted, or depleted, through use but can be replenished with rest. Another important stipulation of the model is that an individual's situational level of resources influences subsequent performance of behaviours that require self-control such that performance suffers when one's resources have been depleted by prior exertion of self-control and requires rest to replenish itself. Interestingly, many studies have shown that self-control depletion can cross over from one domain to another and affect performance on tasks with vastly differing demands (e.g., tasks requiring emotion regulation to tasks requiring muscular endurance), suggesting the resource governing self-control is undifferentiated (Wagstaff, 2014). The strength model has been the basis of hundreds of studies (Baumeister & Vohs, 2016). An early meta-analysis conducted by Hagger, Wood, Stiff and Chatzisarantis (2010) found support for many of the predictions set out by the strength model (Muraven & Baumeister, 2000); however, additional analyses (Carter, Kofler, Forster, & McCullough, 2015) have raised questions about the magnitude and reliability of the effects and there is currently a great deal of controversy that has yet to be resolved. Despite these criticisms, Cunningham & Baumeister (2016) have recently asserted that Carter et al.'s review (2015) included studies laden with questionable sampling, methodological, and data analysis practices, which bring their conclusions into question.

Despite an abundance of research investigating the carryover effects of performing one self-control task on another, there has been little theoretical development in terms of identifying potential mechanisms through which self-control resource depletion can influence behaviour. However, recent evidence suggests fatigue may play an important role. A consistent finding that has emerged in the literature is that people experience higher perceived exertion levels when completing physically-demanding tasks after they have exerted self-control performing mentally- or emotionally-demanding tasks (MacMahon, Schücker, Hagemann & Strauss, 2014; Marcora, Staiano & Manning, 2009; Wagstaff, 2014, Zering, Brown, Graham & Bray, 2017). More specifically, tasks with objectively equivalent physical demands have been found to *feel* harder to do after self-control has been exerted on a prior task. In a recent publication, Graham, Martin

Ginis and Bray (2017) also reported that self-control depletion led to greater perceptions of fatigue, which in turn, mediated the performance reductions observed when participants performed fewer resistance exercises following a cognitive manipulation task that depleted their self-control.

The general purpose of the present study was to delve further into the investigation of self-control exertion and its effects on the performance of an exercise task as well as perceived exertion while performing the task. Ratings of perceived exertion were monitored when participants exercised with experimentally-manipulated levels of self-control. Participants completed three experimental sessions involving sequential tasks. The first visit was used as a familiarization session for all participants. In experimental sessions, both the experimental manipulation task and exercise task were demanding in terms of self-control. In control sessions, only the exercise task demanded self-control. Mental fatigue was also assessed following both manipulation tasks and ratings of perceived exertion (RPE) were assessed throughout the exercise tasks.

Literature Review

Self-control

Over the course of a given day people are required to control behaviours, thoughts and emotions in order to achieve their desires or goals. The strength model posits that in order to exert self-control, one must draw upon a limited resource that can be depleted (Baumeister, Vohs, & Tice, 2007). Depleting the self-control resource causes a weakened state that is referred to as ego depletion or self-control strength depletion (Baumeister, Bratslavsky, Muraven & Tice, 1998). When in an ego-depleted state, attempts to exert self-control show detriments to performance in many tasks that require self-control (Hagger et al., 2010), including exercise and sport performance (Englert, 2016).

A common method for investigating the carryover effects of self-control or ego-depletion on task performance is the sequential dual-task paradigm (Hagger et al., 2010). The archetypal dual-task paradigm compares two conditions, wherein one group of participants completes an ego-depleting task that depletes self-control and the other performs a control task designed to leave self-regulatory resources intact. After completing the initial task, participants in both conditions then complete a task that requires self-control (e.g., response inhibition). Performance on the latter task, which required self-control is then compared between conditions.

Successful self-control of most behaviours is theorized to be dependent upon three core executive functions, including; maintenance of up-to-date information (‘updating’); inhibiting pre-potent responses (‘inhibition’); and mental ‘shifting’ between tasks or mental sets (Hofmann, Schmeichel & Baddeley, 2012). Thus, tasks of varying nature that require executive functioning have been used extensively to investigate self-control depletion within the sequential dual-task paradigm. For example, tasks such as crossing out letters, regulating emotional displays, the modified Stroop task, and thought-suppression have been used to investigate the effects of self-control depletion (Hagger et al., 2010). Additionally, Hagger et al. (2010) noted that across 83 studies, self-control resource depletion in one domain (e.g., emotion, cognition, or behavior) can impact subsequent performance on tasks requiring of the resource within the same domain (e.g., cognitive control → cognitive control) as well as across discrepant domains (e.g., cognitive control → behavioural control), with a moderate to large effect size (Cohen's *d* =0.62). They also observed that self-control depletion had effects on perceived effort, perceived difficulty, negative affect, as well as subjective fatigue during subsequent performances, which provide some direction in terms of psychological mechanisms that may explain why self-control depletion effects may occur (Hagger et al., 2010).

Self-control and Sport/Exercise

Self-control is essential to many activities of daily living, but is also integral to achieving success during training and competitive exercise as well as sport performances (Englert & Bertrams, 2012; Graham, Martin Ginis & Bray, 2017; Kirschenbaum, 1987; McEwan, Martin Ginis & Bray, 2013; Weinberg & Gould, 2014). For example, athletes must often choose to put off inherently gratifying tasks, such as interaction with friends, in order to adhere to training consisting of demanding and less preferable requirements, such as deliberate practice (Jonker Elferink-Gemser, Tromp, Baker & Visscher, 2015). It can also be argued that both training and competition require acute bouts of self-control exertion, as individuals attempt to perform complex and arduous tasks under varying social-, environmental- and performance-related demands. For example, self-control exertion could manifest in pushing oneself in weight training to achieve beyond what was previously accomplished or inhibiting the urge to quit or slacken effort when one falls behind an opponent in a race.

Over the past two decades, many tasks have been used to investigate the effects of self-control depletion on physical performance within the framework of the sequential dual-task paradigm. Specifically, handgrip endurance has been investigated in numerous studies which have revealed consistent negative carryover effects following a variety of cognitive self-control manipulations (e.g., Bray, Martin Ginis, Hicks & Woodgate., 2008; Bray, Martin Ginis & Woodgate, 2011; Bray, Graham, Martin Ginis & Hicks, 2012; Brown & Bray, in press; Graham & Bray, 2015; Seeley & Gardner, 2003).

The literature investigating the effects of self-control depletion on sport and exercise performance was recently reviewed by Englert (2016). Although the author acknowledged that additional research is needed, there is strong evidence that rigorous training sessions have the capacity to temporarily deplete levels of self-control (Gröpel, Baumeister & Beckmann, 2014). Englert also acknowledged that several lines of research have implicated concepts such as motivation (Inzlicht & Schmeichel, 2012) and resource allocation (Beedie & Lane, 2012) as potential modifiers of self-control depletion effects. Further research investigating these factors is necessary; however, there are several studies that point to an interesting relationship between self-control exertion and mental fatigue. Although there is some agreement that mental fatigue is associated with the depletion of self-control resources, there is evidence that one may not preclude the other and self-control depletion tasks result in mental fatigue only when sufficiently long and/or demanding. Englert also recommended that future research should look to assess the impact of self-control exertion on levels of perceived mental fatigue.

Although self-control depletion has been examined in relation to many physical tasks, a recent study conducted by Graham et al. (2017) provided the first experimental account investigating the effect of self-control exertion on fatigue and the performance of resistance exercise. Participants ($N = 50$) were randomly divided into control and experimental condition using single-blind design. Participants in both conditions were required to complete two sets of bench press and leg extensions, with each set separated by a cognitive task manipulation. Participants in the experimental condition were tasked with completing 5-minutes of incongruent Stroop trials designed to deplete self-control. Those in the control group performed a 5-minute congruent version of the Stroop task designed to leave self-control intact.

Following completion of the self-control depletion manipulation, participants reported greater ratings of perceived mental exertion, $p < 0.01$, $d = 2.48$, and higher ratings of fatigue, $p = 0.02$, $d = 0.69$. Additionally, participants expressed lower ratings of task self-efficacy following the experimental manipulation for both bench press, $p < 0.01$, $d = 0.94$, and leg extension, $p = 0.01$, $d = 0.72$. Performance on bench press and leg extension trials were significantly worse following experimental manipulations (*p*s < 0.01). Specifically, experimental participants performed an average of 3.76 fewer bench press repetitions following the self-control manipulation, whereas control participants did not change (Cohen's $d = 1.28$). Moreover, participants in the control group were able to increase their leg extension performance by an average of 0.72 repetitions, while the experimental group performed an average of 2.96 fewer leg extensions, which again resulted in a large effect-size ($d = 0.91$).

After showing these general effects, Graham et al. (2017) then used their data to test a causal mediation model hypothesizing that exerting cognitive control to perform the Stroop task causes fatigue, which in turn leads to lower performance. Their results supported causal mediation, with both fatigue and self-efficacy accounting for the effects of prior self-control exertion on resistance exercise performance. Put simply, their evidence suggests that fatigue and self-perceptions may explain why people show reduced physical capabilities despite the fact that cognitive self-control manipulations do not require any motor unit activation and very little energy expenditure (Graham et al., 2017).

Mental Fatigue & Physical Performance.

Mental fatigue is defined as an altered psychobiological state, which is posited to arise from the cognitive demands of an activity (Boksem & Tops, 2008). Furthermore, the effects of mental fatigue have the capacity to manifest both subjectively, as well as behaviourally. Increased feelings of tiredness/lacking energy (Boksem & Tops, 2008) as well as decreased levels of motivation (Boksem, Meijman & Lorist, 2006) are commonly reported as some of the subjective experiences of mental fatigue. Behaviourally, mental fatigue has been shown to be associated with poorer cognitive performance (Möckel, Beste & Wascher, 2015). However, there is also a growing body of literature documenting deleterious effects of mental fatigue on subsequent physical performance (Marcora et al., 2009; Mosso, 1891; Van Cutsem Marcora, De Pauw, Bailey, Meeusen & Roelands, 2017).

In 1891, an Italian physiologist by the name of Angelo Mosso produced the first experimental design probing the effects of mental fatigue on subsequent physical performance. In his influential book investigating fatigue, Mosso described an anecdote wherein muscular endurance was diminished in two of his colleagues following a day of long lectures and examinations (Mosso, 1891).

The first contemporary study investigating the effects of mental fatigue on physical performance was published over a century later by Marcora and colleagues in 2009 (Marcora, Staiano & Manning, 2009). Using a counterbalanced within-subjects design, Marcora et al. asked highly-trained cyclists to attend their laboratory on two separate occasions. During the experimental session, the pre-exercise manipulation consisted of a 90-minute cognitively-demanding task (AX- Continuous Performance Task; Barch, Braver, Nystrom, Forman, Noll & Cohen, 1997). In the control session, participants watched a 90-minute affectively-neutral video. Following the manipulations, participants performed a stationary cycling task requiring them to cycle at a highly-challenging workload of 80% of their peak power output, until failure. The researchers verified the effect of the cognitive manipulation by assessing changes in mood states related to questions about vigour and fatigue, ps < 0.01. These measures provided evidence of greater subjective fatigue following the experimental task compared to control. The behavioural effects of mental fatigue were also seen in a statistically significant decline in response accuracy during the first 15-minutes of the AX-CPT (94.8 ± 3.4%) compared to the last 15-min period (88.9 ± 4.5%), $p < 0.01$.

Marcora et al. (2009) observed that participants cycled for a significantly shorter duration in the mental fatigue condition ($M = 640 \pm 316$ seconds) relative to control ($M = 754 \pm 339$ seconds; $p < 0.01$). Although a performance decrement was observed, several physiological variables including: heart rate, peak oxygen consumption, and onset of blood lactate accumulation did not differ between conditions. However, one variable that did differ between conditions was participants' ratings of perceived of exertion (RPE). That is, RPE was significantly higher at the onset of the trial and remained higher throughout the exercise task in the mentally-fatiguing experimental condition ($p < 0.01$). Participants reported maximal ratings of exertion at the termination of both exercise tasks; however, those maximal ratings were achieved almost two minutes earlier in the mental fatigue condition. As a result of RPE being impacted by mental fatigue, the authors concluded that perceived exertion can be impacted by central factors (i.e., perceptions of effort) independent from peripheral muscular and/or energy systems.

Since Marcora et al.'s (2009) study was published, several additional studies have investigated the effects of mental fatigue on physical performance. In a study carried out by MacMahon et al. (2014), the effects of mental fatigue on physical performance were investigated using a 3-km running time-trial on a 200-m indoor track as the outcome of interest. Similar to Marcora et al. (2009), these researchers used a counterbalanced design and a sequential task paradigm in which participants ($N = 20$) performed a mentally-fatiguing task or a non-fatiguing control task prior to running each of the 3-km trials. In the study's experimental session, participants performed the AX-CPT for 90 minutes. In the control condition, participants completed 3-mintes of the AX-CPT before and after watching an 84-minute documentary video, for a total duration of 90 minutes. Participants took significantly longer to complete the time trial following the mentally-fatiguing condition ($M = 731 \pm 54.26$s) compared to the control trial condition ($M = 718.56 \pm 48.39$s). In line with Marcora et al. (2009) physiological measures did not differ between conditions; average HR, $t\ (17) = 0.13$, $p > .05$; blood lactate, $t(19) = 1.19$, $p > .05$. However, unlike the results of Marcora et al. (2009), participants did not report differences in RPE between conditions, $F(1, 19) = .001$, $p > .05$. To explain this finding, the authors reasoned that because they did not receive feedback on their running speeds or times during the time trials, participants may have based their speed (or pacing strategy) only on RPE. Thus, maintaining the same RPE in both trials resulted in slower running times in the mental fatigue condition (MacMahon et al., 2014).

Both Marcora et al. (2009) and McMahon et al. (2014) incorporated lengthy self-paced whole-body endurance tasks as the exercise components of their methodological designs. Contrary to those tasks, physical performance tasks requiring repetitive or brief maximal performances have not shown the same negative effects resulting from mental fatigue. In a study conducted by Martin, Thompson, Keegan, Ball & Rattray (2015), participants (*N* = 12) reported to a laboratory for a total of five sessions using a randomized crossover design. Sessions 1-3 of the five study sessions were used to familiarize participants to the study's main performance tasks, which included: countermovement vertical jumps, maximal isometric leg extensions, and a standardized cycle ergometer task (3MT; Vanhatalo, Doust & Burnley, 2007). The final 2 sessions represented the study's control and experimental trials, which were counterbalanced for order of presentation. The experimental manipulation required participants to complete a 90-minute AX-CPT between two blocks of performance on the aforementioned anaerobic tasks. Control trials substituted a 90-min affectively-neutral documentary video for the AX-CPT. Results showed performance remained largely unaffected when participants were mentally-fatigued relative to non-fatigued control trials. Specifically, 3MT performance did not differ between conditions in terms of; peak power ($p = 0.41$, $d = 0.25$); mean power ($p = 0.22$, $d = 0.38$); or estimated anaerobic work capacity ($p = 0.32$, $d = 0.30$). Although there were no significant decrements in performance, there was a small effect of condition on RPE during the 3MT ($p = 0.10$, $d = 0.23$) with higher RPE reported in the mental fatigue condition. However, RPE data was not collected for vertical jump, or leg extension performances. The authors concluded that although mental fatigue may have had a small impact on RPE; it did not impact maximal anaerobic performance.

Recently, a systematic review summarizing studies investigating the effects of mental fatigue on physical performance was published by Van Cutsem and colleagues (Van Cutsem et al., 2017). The review was constrained to studies employing cognitive tasks ≥ 30 minutes in length (range = 30 - 100 min.) and using a sequential dual-task paradigm. The exclusion of studies involving manipulations of less than 30 minutes was based on findings reported by a multi-laboratory collaboration, which failed to replicate the self-regulation depletion effect with shorter duration tasks (Hagger et al., 2016) and a study conducted by Nuechterlein, Parasuraman & Jiang (1983) was used to determine a minimum manipulation duration of 30-minutes for the purposes of the systematic review.

In total, Van Cutsem et al. (2017) reviewed 11 studies that met the required inclusion criteria. All studies included in the review used demanding cognitive tasks, requiring consistent focus and attention for the duration of the respective trials. These tasks included: the Switch Task Paradigm, concentration grids, the incongruent Stroop Task, as well as the AX-CPT. A summary of the studies included in the review is provided in Table 1**.** Generally, the studies demonstrated negative carryover effects of mental fatigue on endurance cardiovascular performance. However as noted earlier, the effects of mental fatigue were not seen in studies involving anaerobic performance tasks or brief, repetitive tasks that do not involve sustained regulation of effort over prolonged periods of time. Importantly, this review also concluded performance changes experienced as a result of mental fatigue are predominantly associated with or mediated by higher than normal perceptions of effort or RPE (Van Cutsem et al., 2017).

Table 1

Summary of Mental Fatigue Studies using Manipulations of Greater than 30 Minutes.

Publication	Cognitive Task	Cognitive Task Duration	Physical Task	Performance Outcome	RPE Outcome
Marcora et al., 2009	AX-CPT	90-min.	TTE – Cycling	Performance ↓	RPE ↑
Pageaux et al., 2013	AX-CPT	90-min.	Isometric Leg Extensions	Performance ↓	RPE ↑
Brownsberger et al., 2013	AX-CPT	90-min.	Self-paced Cycling	Performance ↓	RPE =
MacMahon et al., 2014	AX-CPT	90-min.	3km TT – Running	Performance ↓	RPE ↑
Pageaux et al., 2014	Stroop	30-min.	5km TT – Running	Performance ↓	RPE ↑
Budini et al., 2014	Switch-Task	100-min.	Isometric Leg Extension	Performance ↓	N/A
Duncan et al., 2014	Concentration Grids	40-min.	TTE – Cycling	Performance =	N/A
Pageaux et al., 2015	Stroop	30-min.	TTE – Cycling	Performance =	RPE ↑
Smith et al., 2015	AX-CPT	90-min.	Self-paced Running	Performance ↓	[a]RPE =; [b]RPE ↑
Martin et al., 2015	AX-CPT	90-min.	CMJs, Leg extensions, 3MT	Performance =	RPE ↑
Smith et al., 2016	Stroop	30-min.	Yo-Yo IR1	Performance ↓	RPE ↑

Note. Time-to-exhaustion (TTE). Ratings of Perceived Exertion (RPE). Time trial (TT). Yo-Yo IR1; repeated interval running over a prolonged period of time. Countermovement jumps (CMJ). 3MT cycle ergometer task (Vanhatalo et al., 2007). [a]RPE measured during task, [b]RPE measured 30-min following exercise.

Van Cutsem and colleague's review (2017) provides a comprehensive scan of the literature investigating demanding cognitive manipulations exceeding 30-minutes in length. As mentioned earlier, Van Cutsem et al. (2017) purposely did not include studies involving cognitive manipulations of less than 30 minutes. Curiously, that decision was based on a study (Hagger et al., 2016) that did not involve a physical performance task. Indeed, there is an extensive body of literature showing that physical performance decrements can also be experienced following performance of demanding cognitive tasks that are much shorter in duration. However, many of these studies were based on the strength model of self-control, which does not explicitly identify mental fatigue as a core construct, but does include a similar concept of subjective fatigue as a potential mediating mechanism (Baumeister & Vohs, 2016; Hagger et al., 2010).

In one of the first studies to examine the potential negative carryover effect of self-control strength depletion on physical performance, Bray, Martin Ginis, Hicks and Woodgate (2008) investigated the effects of a cognitively-demanding task on endurance handgrip squeezing performance, using in a sequential dual-task paradigm. Participants ($N = 49$) completed two maximum endurance handgrip contractions (at a constant load of 50% of their maximum voluntary contraction). In between the two endurance contractions participants in the experimental group performed a modified incongruent Stroop task for three minutes and 40 seconds whereas those in the study's control condition completed a congruent version of the Stroop task for the same duration. Results showed significant differences in handgrip endurance performance between conditions with depleted individuals (time-to-failure = 32.29s) exhausting sooner than controls (time-to-failure = 46.12s), $F(1, 47) = 6.92$, $p < 0.01$. Ratings of perceived exertion were obtained at the completion of each of the endurance handgrip trials. RPE was not different at the end of the first trial (prior to the cognitive manipulation), nor was RPE different at the end of the second trial, $p > 0.10$, indicating participants in the experimental condition exerted the same maximal effort despite performing worse on the second endurance task.

In another illustrative study showing the effects of a brief cognitive control manipulation on physical performance, Zering and colleagues (2017) investigated the effects of a brief cognitively-demanding task on the performance of subsequent whole-body cardiovascular exercise. In contrast to the Bray et al. (2008) study, this study made use of a crossover design. Experimental trials required participants to complete 10.5-minutes of a computerized stop-signal task (Stop-It^{TM}; Verbruggen, Logan, & Stevens, 2008), prior to completing a graded exercise test (GXT) on a cycle ergometer. Control trials followed the same methodology, however a 10.5-minute affectively-neutral video replaced the stop-signal task. Participants also reported ratings of perceived mental exertion following the experimental manipulation. Relative to the control task ($M = 1.29 \pm 1.36$) mental exertion was significantly higher following the stop-signal task ($M = 4.37 \pm 1.92$), $F(1,14) = 46.140$, $p < 0.01$, $\eta_P^2 = 0.767$. Following the experimental manipulation, participants generated lower peak power outputs on their GXTs compared to control GXTs, $F(1, 13) = 12.830$, $p < 0.01$, $\eta_P^2 = 0.497$. Decrements in performance occurred in the absence of any significant physiological differences between conditions: peak HR, $p = 0.50$, $\eta_P^2 = 0.05$; breathing frequency, $p = 0.59$, $\eta_P^2 = 0.02$; and tidal volume, $p = 0.34$, $\eta_P^2 = 0.07$. Ratings of perceived exertion during the GXT's; however, were significantly higher following the mentally-fatiguing task, $F(2.293, 32.101) = 210.708$, $p < 0.01$, $\eta_P^2 = 0.938$. This study provides further evidence that brief cognitively-demanding manipulations are sufficient to negatively impact performance of whole-body cardiovascular exercise and increase RPE during exercise.

A third illustration of the effect of brief cognitively-demanding tasks on subsequent physical performance is a recent study conducted by Brown & Bray (in press). In this study, the researchers investigated whether there might be dose-response relationship between cognitive task duration and subsequent physical performance. Participants (N = 123) performed two endurance isometric handgrip trials, which were separated by a cognitive task manipulation. Participants were randomly allocated to one of six conditions, which represented different durations of exposure to the task requiring cognitive control. All participants were exposed to a 12-minute, no-exercise, manipulation window between handgrip trials, where they completed 0, 2, 4, 6, 8, or 10 minutes of the incongruent Stroop task. Fatigue was assessed following the cognitive manipulations and revealed that ratings of subjective mental fatigue increased proportionately relative to time-on-task in conditions that performed more than 4 minutes of the cognitive task. The control condition (0-minutes Stroop) differed significantly from all groups receiving ≥ four-minutes of Stroop exposure (all ps < 0.05), illustrating that the onset of mental fatigue did not occur until after two-minutes of task exposure. However, mental fatigue did increase linearly with greater exposure to the Stroop task. Contrary to the linear dose-response effect of mental fatigue on performance hypothesized by the researchers, the results showed a threshold effect. Specifically, reductions in handgrip performance following the cognitive manipulation were only evident in groups that performed greater than four-minutes of the Stroop task. In the groups that performed the Stoop task for six minutes or longer, the performance decrements were significant, but did not differ across the six, eight and ten-minute conditions. Ratings of perceived exertion reported at the end of the handgrip task did not differ between conditions, despite the differences in objective performance, which is consistent with the findings of Van Cutsem et al. (2017) showing performance declines can occur despite similar levels of RPE. Overall, these results provide important evidence that mental fatigue or self-control depletion manipulations may need to be of sufficiently long duration or sufficiently high intensity to produce significant effects on mental fatigue and performance.

The three studies described above attempt to illustrate some of the main characteristics of the research utilizing brief cognitively-demanding manipulations and their aftereffects on the performance of physically-demanding tasks. A more elaborative summary of studies utilizing cognitive tasks shorter than 30-mintes (omitted from Van Cutsem et al., 2017) is provided in Table 2**.** Across these studies, it is evident that performance on physical tasks is negatively impacted by cognitively-demanding, mentally-fatiguing manipulations. Interestingly, studies using shorter manipulations also show evidence of higher RPE while performing exercise tasks following cognitively-effortful tasks compared to control tasks (Brown & Bray, in press; Graham et al., 2017; Zering et al., 2017).

Table 2

Summary of Mental Fatigue Studies using Manipulations of Less than 30 Minutes.

Publication	Cognitive Task	Cognitive Task Duration	Physical Task Description	Performance Outcome	RPE Outcome
Seeley & Gardner, 2003	Thought Suppression	5-min.	Isometric HG	Performance ↓	N/A
Bray et al., 2008	Stroop	< 4-min.	Isometric HG	Performance ↓	RPE =
Martin Ginis & Bray, 2010	Stroop	< 4-min.	Maximum Work Output - Cycling	Performance ↓	N/A
Bray et al., 2011	Stroop	< 4-min.	Isometric HG	Performance ↓	N/A
Bray et al., 2012	Stroop	22-min.	Isometric HG	Performance ↓	N/A
Dorris et al., 2012	Arithmetic*	10 min.*	Press-ups, Sit-ups	Performance ↓	N/A
McEwan et al., 2013	Stroop	5-min.	Dart Throwing Accuracy	Performance ↓	N/A
Wagstaff et al., 2014	Emotion Suppression	3-min.	10km TT – Cycling	Performance ↓	RPE ↑
Graham & Bray, 2015	Stroop	5-min.	Isometric HG	Performance ↓	RPE =
Zering et al., 2016	SST	10.5-min.	GXT – Cycling	Performance ↓	RPE ↑
Schücker & MacMahon, 2016	Stroop	10-min.	Shuttle Run	Performance =	RPE =
Graham et al., 2017	Stroop	5-min.	Bench Press, Leg Extensions	Performance ↓	RPE ↑
Brown & Bray, in press	Stroop	< 4-min.	Isometric HG	Performance =	RPE =
		> 6-min.	Isometric HG	Performance ↓	RPE =

Note. Handgrip (HG). Time Trial (TT). Stop-Signal Task (SST). Graded Exercise Task (GXT). *Dorris et al.'s cognitive manipulation utilized arithmetic in conjunction with a physical level balancing demand; duration varied by participant.

One of the key findings in Van Cutsem et al.'s (2017) review and the studies reviewed in Table 2 is the interaction between physical performance and RPE. That is, one of three patterns of response appear to emerge: 1) Performance declines and RPE increases, 2) Performance is the same and RPE increases, or 3) Performance declines and RPE is the same. However, one potential limitation of this body of research is that RPE has been operationalized as an holistic, gestalt-representation of exertion (Marcora et al. 2009; MacMahon et al., 2014; Martin et al., 2015). It has been recognized for some time that RPE is a construct that can apply to multiple interoceptive domains (Borg, 1998). Indeed, Borg (1998) notes that when RPE is solicited in single-item manner from the 16-point or CR-10 scales, the rating can derive from sensations emanating from muscles or joints; from somatosensory receptors; from cardiorespiratory systems; or even from other bodily organs. Consequently, a singular rating could oversimplify a complex psychophysiological experience. It has been further argued that disentangling the perceptions of exertion from distinct sensory inputs may provide greater resolution to the phenomenon being observed (McLaren, Smith, Spears & Weston, 2017).

Research in the field of applied physiology routinely has participants provide RPE for local, or peripheral, and central exertion (Borg, Ljunggren & Ceci. 1985; Demura and Nagasawa 2003; Robertson, Gillespie, McCarthy & Rose, 1979). By orienting participants to report exertion levels regarding discrete sensory modalities, differential RPE (dRPE) is argued to provide more information than a single gestalt rating of perceived exertion (McLaren et al., 2017). Recently, sport and exercise psychologists have started implementing dRPE methodology into experimental sessions (Los Arcos, Yanci, Mendiguchia & Gorostiaga, 2014; McLaren et al., 2017). McLaren and colleagues (2017) compared dRPE relative to holistic sessional ratings of perceived exertion. Professional rugby players (*N* = 29) completed a 6-week training program, with each session consisting of different exercise tasks. At the end of each session, participants were asked to provide a gestalt rating of RPE for the session along with dRPE ratings for; breathlessness, leg-muscle exertion, upper-body exertion as well as cognitive demands. As a result of the different demands across the various exercise tasks used in the study, dRPE scales provided unique insights into task demands compared to the gestalt RPE scores. Specifically, holistic ratings of RPE typically matched the dRPE modality that best represented the demands of the exercise task. For example; leg muscle ratings of exertion best explained performance in high-intensity interval training whereas cognitive/technical ratings were better at explaining the performance observed during speed and skills sessions training. The researchers concluded that tasks with differing task demands also elicit differing exertion demands and that the use of dRPE has the capacity to provide more granular insight into the experiences of athletes in a variety of performance scenarios (McLaren, Smith, Spears& Weston, 2017). The present study seeks to build upon these findings and is the first to investigate differential RPE during exercise with and without mental fatigue.

The effect of mental fatigue or self-control depletion on physical performance and feeling states such as RPE experienced during exercise is clearly of interest to researchers, but the potential carryover effects of mental fatigue on physical performance is also an important consideration for athletes and coaches. The studies summarized thus far provide a comprehensive account for the deleterious effects of contrived cognitive manipulations on a multitude of physical tasks using the sequential dual-task paradigm (e.g., Bray et al., 2008; Marcora et al., 2009). However, it is important to recognize that "real-world" athletes are seldom asked to complete computer-based cognitive tasks prior to performances.

In order to address this limitation Wagstaff (2014) designed a protocol that aimed to incorporate a cognitive manipulation requiring participants to control their emotions in a challenging situation and a physical performance task that required complex, whole-body behaviours (Wagstaff, 2014). In a randomized, counterbalanced design, participants ($N = 20$) completed cognitively-demanding tasks or non-demanding control trials, before ultimately performing a whole-body endurance cardiovascular exercise task. In both conditions, participants were required to watch a 3-min. video excerpt, which showed an Asian woman causing herself to vomit and subsequently eat her own vomit. The experimental condition required that participants watch this noxious stimulus, and regulate their emotions by showing no facial or behavioural cues of emotion. In control trials, participants were free to react as they would normally (e.g., show disgust). Following the cognitive task in both conditions, participants were required to ride cycle ergometer and complete a 10-km time trial in as short a duration as possible. Results showed subjective fatigue immediately following cognitive tasks did not differ between conditions, $F(1, 18) = 0.66$, $p = 0.43$, $\eta^2 = 0.04$. However, performance on the 10-km time-trial was significantly worse following emotion suppression ($M = 18.42 \pm 1.14$ min.), relative to controls ($M = 17.82 \pm 1.08$ min.), $p < 0.01$, $d = 0.52$. RPE was also significantly higher in experimental trials ($M = 16.34 \pm 0.64$), relative to controls ($M = 15.34 \pm 1.02$), $p < 0.01$, $d = 0.72$. It is interesting to note that in this study fatigue did not explain the decrements in performance elicited by the study's cognitive manipulation; however, the task did have a strong emotion regulation component and was also very brief (i.e., 3 minutes), which Brown and Bray (2017) have shown may be too brief to induce a state of mental fatigue.

Engaging in effortful self-regulation prior to exercising has the capacity to influence performance in whole-body cardiovascular endurance tasks by inducing a state of cognitive fatigue (Van Cutsem et al., 2017). However, tasks requiring self-control can take many forms. Thus, Wagstaff's (2014) study is instrumental in illustrating that trying to control an instinctive or habitual reaction to a challenging emotional situation can lead to sub-optimal performance. Athletes in competitive situations are often faced with situations where controlling emotions such as anxiety is necessary (Woodman & Hardy, 2003). However, athletes in practice and competition also need to control their thoughts as negative thoughts (e.g., what if I miss this putt?) can have detrimental effects on motivation and performance (Beilock, Afremow, Rabe & Carr, 2001).

Thought-suppression is cognitive function that has been shown to involve self-control resources (Muraven, Tice & Baumeister, 1998; Studies 2 and 3). There is also an extensive literature on thought suppression (Wenzlaff & Wegner, 2000). One of the first contemporary studies to investigate thought suppression asked participants to attempt suppressing the thought of a white bear while completing a 5-min. bout of logging thoughts (Wegner, Schneider, Carter & White, 1987). The researchers determined that the act of thought suppression resulted in similar net occurrences of the forbidden thought relative to controls who were allowed to think freely. Interestingly, in subsequent bouts of thought-logging – those that were required to initially suppress the thought of a white bear were observed to report significantly more intrusions of the erroneous cognition, relative to controls who were not required to exert self-control. In line with the strength model of self-control (Baumeister & Vohs, 2016), these results implicate the notion that initial exertion of self-control (suppression) is followed by a diminished capacity to continue exerting self-control.

In 1998, Muraven et al. (1998) published a series of studies that further implicated the exertion of self-control with the act of thought-suppression. In one illustrative study (study 2), participants in an experimental group were asked to complete an unsolvable anagram task theorized to require self-control following a short bout of thought suppression, using the previously described white bear methodology (Wegner, Schneider, Carter & White., 1987). As a manipulation check, participants were asked to assess how much self-regulatory effort they exerted, as well as how hard they found both the experimental and control (free thought-logging) conditions. Participants reported exerting significantly more self-control when suppressing thoughts relative to controls, $t(32) = 3.36$, $p < 0.01$. Thought-suppression was also perceived to be significantly harder relative to bouts of free thought-expression, $t(32) = 2.37$, $p < 0.03$. These effects translated to performance on the anagram task with experimental participants quitting sooner on the task, relative to controls, $t(32) = 2.18$, $p < 0.05$. The researchers concluded that the self-control demands placed on participants suppressing thoughts ultimately lead to earlier withdrawal from the anagram task due to reductions in self-control strength caused by thought suppression (Muraven et al. 1998; Study 2).

In the field of sport psychology, several techniques have been developed by interventionists to have athletes control their thoughts (e.g., thought replacement/swapping or thought-stopping). For example, thought stopping techniques train athletes to cope with negative cognitions or self-talk by teaching them to use a verbal trigger in order to suppress unwanted thoughts (Zinsser, Bunker & Williams, 2010). However, the literature showing that thought suppression may consume mental resources that can affect later acts of self-control causes concern that thought suppression techniques may actually have counterproductive effects when exercise or sport performance tasks require self-control to perform. This study investigates the potential for a negative carry-over effect of thought suppression on exercise performance.

Statement of the Problem

The purpose of the current study was to investigate the effects of thought suppression on task performance and differential ratings of perceived exertion (dRPE) during self-paced whole-body exercise. In a repeated-measures design, participants were randomized and counterbalanced to two conditions. In the experimental condition participants completed a thought suppression task, theorized to fatigue self-regulatory resources. In the control condition, participants were allowed to think of whatever they wished. Following each manipulation, participants rode a self-paced maximum-distance trial on a cycle ergometer for 20-minutes with a goal to ride as great a distance as possible and provided dRPE in terms of: leg-muscle exertion (RPE-L), respiration exertion (RPE-R), and mental exertion (RPE-M) throughout each MDT.

Hypotheses

Based on the findings reviewed above, it was hypothesized that there would be an interaction between performance on the exercise task and RPE. Specifically, because the pace and workload of cycling task was self-controlled, it was predicted that either a) performance would be worse and RPE would be unchanged or b) performance would be the same and RPE would be increased, in the thought suppression condition compared to the control condition. Further, because intense stationary cycling requires both muscular and respiratory effort, based on McLaren et al.'s (2017) findings, it was hypothesized that if performance was the same on both trials that RPE-L and RPE-R would be higher during the trial following thought suppression or should performance be worse as a result of mental fatigue, it was hypothesized that both RPE-L and RPE-R would not differ between conditions. Because the cycling task requires minimal cognitive processing, RPE-M was predicted to be lower than RPE-L and RPE-R on both trials. However, it seems plausible that the mental effort required by the exercise could be increased after the mentally-fatiguing thought-suppression task. Therefore, it was predicted that RPE-M would also be higher during the trial following thought suppression if performance was the same on both trials.

Method

Participants

Participants were 16 (n = 8 women) recreationally-active university students (M_{age} = 20.94; range = 17-25). Inclusion criteria specified that all participants must be currently be engaging in ≥ 150 minutes/week of *moderate-vigorous* physical activity at the time of recruitment. All participants reported 20/20 visual acuity; or vision corrected to 20/20 acuity to ensure their ability to see and accurately report on measures placed in front of them. Inclusion criteria also stipulated participants could not currently be taking any prescription medication, with the exception of oral contraceptives. Prior to study intake all participants were screened for contra-indicators of performing moderate-vigorous intensity exercise using the Physical Activity Readiness Questionnaire (PAR-Q; Thomas, Reading, & Shephard, 1992). Participants provided informed consent and the study protocol was reviewed and approved by an institutional research ethics board. Participants received $30 compensation for their contributions to the study.

Tasks, Measures, and Apparatus

Maximum Distance Trial (MDT). The focal behavioural outcome variable was a maximum distance/work trial performed on a cycle ergometer (Lode Corival, Groningen, The Netherlands). The ergometer was fitted to each participant so that their leg was close to full extension on the downstroke while pedaling (145-155 degrees); a standard reported for high intensity exercise by Peveler and Green (2011). The ergometer's handlebars were adjusted for individual comfort. All participants completed a three-minute warm-up at a 50 Watt (W) workload, during which time they were asked to complete pre-task measures. Following warm-up, researchers then switched the ergometer from terminal mode (computer-defined), to manual mode (user-defined). For the participants' reference, researchers adjusted the ergometer's starting load to reflect the same demands as the warm-up (i.e., 50 W). Once the reference load was established, participants were tasked with riding for 20-minutes with the goal to cover the most distance/produce the most energy as possible. It was explained to all participants that the ergometer workload dictates performance on a task of this nature (i.e., high loads would result in longer distances traveled than lower loads). Therefore, to cover a greater distance in the same amount of time, workload had to be increased. The cycle ergometer was set to "hyperbolic" mode, which automatically adjusts resistance such that only changes in the workload setting (not pedaling speed) would affect performance. Online feedback was provided for elapsed time; however, participants were blinded to workload as well as RPM throughout the trials. No motivational encouragement was provided at any time during testing. Moreover, only discourse pertaining to task demands was allowed between participants and researchers during the MDT. The primary outcome of the MDT was total distance (in metres) travelled over the course of 20 minutes, which was automatically recorded on the ergometer software. Immediately following the MDT, researchers switched the ergometer back to terminal mode where the protocol automatically adjusted the bike load to 50 W for a cool-down. Participants then filled out post-task measures as they pedalled for 5 minutes.

Physiological measures

Heart rate (HR). HR was measured as beats/minute using a Polar heart rate monitor (H7 transmitter; Polar Electro OY, Kempele, Finland). HR data were recorded at 30-second intervals throughout the experimental sessions, representing average HR for the current 1-second sampling window.

Manipulations

Both control and experimental conditions were adapted from procedures defined by Muraven et al. (1998). In order to best replicate the methods reported by Muraven et al. (1998), Muraven provided a transcript of the script used in their study (Muraven, personal communication, November 22, 2016). Generally, participants were told to write down thoughts as they came to mind. Samples were stratified by gender and counterbalanced for condition order.

Control. *The study's control condition asked participants list all their thoughts for a 6-minute period. Prior to performing the task, participants were instructed the following: "I would like you to write down any words that come to your mind on this piece of paper. Whatever pops in your head write down. Don't worry about anyone seeing what you write; your name won't be on it and I will put it in a big stack with a bunch of other papers, so I will never know what you wrote."*

Experimental. *For the experimental condition manipulation, participants performed an adapted version of the White Bear thought-suppression task (Wegner et al., 1987), which required them to complete the same 6-minute thought-logging task from the control condition. In addition to thought-logging, they were also instructed to avoid thinking about a white bear and to record any instances when a thought of a white bear occurred. In addition to the thought-logging instructions, the researcher also stated:*

"There is one additional thing. As you write down your thoughts, I want you to try not to think about a white bear. Do your best to put the thought of a white bear out of your head. Any time the thought of a white bear enters your mind try to push it aside. Don't think about a white bear. Any time you do think about a white bear, put a check mark on

the paper near where you are writing. Do you have any questions? Do you understand what you are going to do? Write down your thoughts on this piece of paper, trying not to think about a white bear. Anytime you think of a white bear, put a check mark on the paper. I will stop you in a few minutes." (Muraven, personal communication, November 22, 2016)

In cases where participants' experimental sessions preceded the thought-log control trials (1/2 participants) – there is a potential that participants would be primed to think of a white bear in successive thought-logging bouts. The control condition inherently imposed no restrictions on thought content, and as a result any intrusion of a primed thought would not be met with the requirement that it be suppressed. As such, no exertion of self-control would be required as anticipated in the suppression condition. An fMRI study by Mitchell, Heatherton, Kelley, Wyland, Wegner & Macrae (2007) substantiates the notion that the suppression of a primed-thought prompts greater activation in neural structures related to self-control, relative to the mere presence of the cognition.

Manipulation checks and potential covariates

Ratings of perceived exertion. Ratings of perceived exertion (RPE) served as an indicator of effort exerted on the physical endurance tasks. RPE was recorded using Borg's CR-10 scale (Borg, 1998). Participants were instructed to rate their perception of exertion, that is, how heavy or strenuous the exercise felt to them based on the strain and fatigue (Borg, 1998, p. 47) using a scale ranging from 0 (no exertion at all) to 10 (maximal exertion) at 1-minute intervals during each endurance trial. An instruction sheet outlining scale usage as prescribed by Borg (1998) was provided to all participants in their familiarization session. After being asked to read the instructions over, the several conceptual questions were posed to participants to ensure they understood the nature of the scale. For example, participants were asked – using the CR-10 scale, “How black do you perceive a piece of pure black charcoal to be? How white?” (Borg, 1998). When the experimenter was confident participants understood how to properly use the CR-10 scale by means of 5 conceptual questions, additional instructions followed regarding differential ratings of perceived exertion (dRPE).

As described in several studies (Los Arcos et al., 2014; McLaren et al., 2017), participants were asked to report dRPE with reference to discrete sensory inputs including: respiratory (RPE-R), leg muscle (RPE-L) and mental (RPE-M) exertion. In addition to an experimenter-led discussion about scale requirements, participants were prompted with the following instructions: "*When reporting on respiration exertion, consider; depth of breath, rate of breath, and quality of breath. When reporting on muscle exertion, consider; muscle tension, soreness, muscle responsiveness. When reporting on mental exertion, consider; your mental effort required to persist during the task, your attention, as well as your focus*." Participants then verified that they were comfortable using dRPE methods for all three modalities.

Subjective Mental Fatigue. To assess mental fatigue, a Visual Analogue Scale (VAS; Wewers & Lowe, 1990) was employed. Participants were asked: “Please mark (X) on the line the point that you feel represents your perception of your current state of mental fatigue”. The response continuum consisted of a 100-mm line with the anchors ranging from ‘none at all’ on the left-hand side corresponding with 0 and ‘maximal’ on the right-hand side corresponding with 100. Scores were calculated by measuring the distance (in millimeters) that the ‘X’ was placed from the left side of the scale.

Task Load. The National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988) was used to assess participants ratings of subjective workload. The NASA-TLX is made up of six subscales designed to quantify ratings of a task's: Mental, Physical, Temporal, Performance, Effort and Frustration demands. Participants completed the NASA-TLX after thought-logging and thought-suppression cognitive tasks.

Design & Procedures

This study utilized a randomized crossover design. Participants were stratified by gender and randomized to the order of exposure with half completing the experimental manipulation task first and half completing the control manipulation task first. All participants attended three laboratory testing sessions at the same approximate time of day, each separated by ≥ 72 hours. Participants were asked to consume similar meals at similar times on each testing day and refrain from consuming caffeine for 4 hours prior to each testing session. Participants were also asked to arrive to sessions having hydrated sufficiently for endurance physical tasks.

The first lab visit was used as a familiarization session, designed to introduce all participants to the MDT, as well as the various psychological and psychophysical measures being collected. Importantly, the session served as an opportunity to introduce to the concepts and methods of rating different sensations of perceived exertion (RPE). Upon arrival at the first session, participants were given a thorough explanation of procedures and provided informed consent. Height (cm) and weight (kg) were assessed using a tape measure and a digital scale, respectively. Participants were then fitted with a heart rate monitor (Polar H7, Polar Electro OY, Kempele, Finland). Ergometer seat height was determined by assessing participants' knee-angles via goniometer (Peveler & Green, 2011). After the set-up of the ergometer was complete, participants mounted the ergometer and were instructed to pedal at a comfortable cadence as the researcher set the workload setting to 50W for the 3-min warm-up. Upon completion of the warm-up, the ergometer settings were changed and participants completed the 20-minute MDT.

HR was monitored continuously and was recorded at 30-second intervals during the MDT and participants provided RPE ratings (RPE-R, RPE-L, RPE-M) every minute, beginning 30 seconds into the MDT. Upon completion of the MDT, the researcher adjusted the controls on the ergometer to a workload setting of 50W and the participants performed a cool-down for 5 minutes and then scheduled their second session with the researcher.

Upon arrival at the lab for the second and third sessions, participants were first fitted with a HR monitor and completed the baseline measure of mental fatigue. Participants then performed either the thought-logging (control) or thought-logging + thought suppression task for 6-minutes. Following the experimental/control manipulations, participants provided post-task ratings of mental fatigue and the NASA TLX and then completed the warm-up, MDT, and cool-down in the manner described in the familiarization session. Upon completion of the cool-down, participants either scheduled their third visit, or if it was their final visit, were debriefed and thanked for their participation in the study.

Sample Size Calculation

Sample size for the experiment was calculated via a priori analysis, predicting a main effect for the experimental condition on Performance/RPE on the MDT. Using statistical software (G*Power; Faul, Erdfeller, Lang & Buchner, 2007), a sample size prediction was calculated for a design utilizing repeated-measures analysis, with power = 0.80, alpha = 0.05, and a medium effect size of self-control depletion on subsequent exertion of the resource (d = 0.65; r = 0.31 based on Hagger et al., 2010). Based on these parameters, a sample size of 15 would be sufficient.

Data Analysis

Descriptive statistics were computed for all variables and preliminary data screening was carried out to evaluate the distributions of the scores for each primary dependent variable in terms of normality. As a manipulation check, a paired samples *t*-test was computed to compare the number of thoughts listed during the thought-listing task for the experimental and control conditions. A paired samples *t*-test was also computed to compare the number of thoughts of a white bear listed during the thought-listing task for the experimental and control conditions. A 2 (condition) X 2 (time; pre-post manipulation) mixed-ANOVA was computed to assess the effects of the manipulations on mental fatigue scores. Scores for each item (Mental, Performance & Effort demands) from the NASA-TLX were assessed, independently, using paired-samples *t*-tests.

Prior to carrying out the primary analyses for the hypothesis tests, separate 2 (condition) X 2 (order) mixed-ANOVAs were computed for: Distance Travelled, RPE-L, RPE-R and RPE-M, using order as a between-groups factor to assess the effects of order (main effect and condition X order interaction). Those preliminary analyses are summarized in Tables 7 and 8. There were no significant main effects of order and no significant condition X order interactions. The effect of condition on Distance Travelled was evaluated using a one-way, repeated-measures ANOVA. The effects of the experimental manipulation on heart rate (HR) during the MDTs were assessed in two ways. First, using a one-way, repeated-measures ANOVA of the average HR collapsed across the 40 measurement points collected during each MDT. Second, using a one-way, repeated-measures ANOVA of the 40 measurements collected during each MDT. The second analysis allowed insight as to whether there were different trajectories of change in HR over time during the MDTs (i.e., condition X time interaction). The effects of the experimental manipulation on ratings of perceived exertion (RPE-L, RPE-R and RPE-M) during the MDTs were assessed in two ways. First, using separate one-way, repeated-measures ANOVAs for each RPE variable represented by the average of RPE scores collapsed across the 20 measurements collected during each MDT. Second, using separate one-way, repeated-measures ANOVAs for each RPE variable represented by each of the 20 measurements collected during each MDT. The second analysis allowed insight as to whether there were different trajectories of change in RPEs over time during the MDTs (i.e., condition X time interaction).

Results

Data screening and Assumption Checks

All data were screened for normality. Generally, ranges of skewness and kurtosis and fell within the ranges of -1 to +1, and -2 to +2, respectively. Summaries of the normality tests for Distance Travelled, HR, Workloads, RPMs and each of the RPE variables (represented as mean scores for each MDT) are presented in Table 3. As shown in the table, skewness and kurtosis were within acceptable ranges (Field, 2009).

Table 3

Skewness, Kurtosis and Normality Tests

	Condition	*Skewness*	*Kurtosis*	*Shapiro-Wilk*	*df*	*p*
Distance Travelled	Con.	-0.10	-0.44	0.97	16	0.82
	Exp.	-0.12	-0.84	0.97	16	0.79
HR	Con.	0.30	-0.04	0.98	16	0.99
	Exp.	-0.51	-0.28	0.95	16	0.55
RPE-L	Con.	0.15	-0.85	0.96	16	0.58
	Exp.	-0.01	-1.33	0.94	16	0.31
RPE-R	Con.	0.48	-0.38	0.94	16	0.33
	Exp.	0.35	-0.90	0.94	16	0.35
RPE-M	Con.	0.40	-0.60	0.95	16	0.50
	Exp.	0.83	0.18	0.92	16	0.19
Workload	Con.	-0.06	-0.32	0.97	16	0.86
	Exp.	-0.11	-0.80	0.97	16	0.83
RPM	Con.	-0.09	-0.36	0.95	16	0.52
	Exp.	-0.90	-0.37	0.92	16	0.20

Note. Heart rate (HR). Leg-muscle RPE (RPE-L), Respiration RPE (RPE-R), Mental RPE (RPE-M), Rotations per minute (RPM).

Summaries of the normality tests for each of the RPE variables (represented as individual point scores for each interval for each MDT) are presented in Table 4. As shown in the table, skewness and kurtosis were within acceptable ranges (George & Mallery, 2010) for the majority of data points. According to Glass, Peckham & Sanders. (1972), repeated-measures ANOVA is robust to violations of normality, provided the majority of variables have normally-distributed scores. Therefore, these minor violations of normality were considered acceptable and no transformations were carried out.

Table 4

Normality Test Summaries

	Condition	*Skewness (Range)*	*Kurtosis (Range)*	*Shapiro-Wilk Violations*	*Proportion Violated*
RPE-L	Con.	-0.11- 1.73	-1.43 - 2.99	4	20%
	Exp.	-0.44 - 1.74	-1.62 - 4.50	4	20%
RPE-R	Con.	0.08 - 2.14	-1.25 - 5.33	4	20%
	Exp.	-0.19 - 1.30	-1.65 - 1.33	3	15%
RPE-M	Con.	0.27 - 1.46	-1.30 - 1.59	4	20%
	Exp.	0.29 - 1.75	-1.33 – 3.13	9	45%
HR	Con.	-0.47 - 0.43	-0.96 - 1.08	0	0%
	Exp.	-1.19 - 0.31	-0.92 - 2.06	0	0%
Workload	Con.	-2.51 - 0.60	-1.03 – 4.90	1	5%
	Exp.	-4.00 - 0.39	-1.23 –16.00[a]	1	5%
RPM	Con.	-0.89 - 0.13	-1.14 - 1.06	0	0%
	Exp.	-1.23 - 0.91	-0.79 – 1.58	4	20%

Note. Heart rate (HR). Leg-muscle RPE (RPE-L), Respiration RPE (RPE-R), Mental RPE (RPE-M), Rotations per minute (RPM). [a]Workloads at bout initiation and termination were highly variable as a function of individual difference, but constituted a minority of cases

Manipulation Checks

Thought-listing task. The number of thoughts listed by participants in both control and experimental conditions are reported in Table 5. Results of the paired-samples *t*-test showed no significant differences in the number of thoughts listed, *t*(15) = 0.54, p = 0.60, *d* = 0.14. A mixed-ANOVA using order as a between-subjects factor determined no significant main effect of condition on the volume of thoughts listed by participants, *F*(1,14) = 0.27, *p* = 0.61, η^2 = 0.02. The model resulted in a non-significant main effect of order, *F*(1,14) = 2.46, *p* = 0.15, η^2 = 0.15. This was also true of the condition X order interaction, *F*(1,14) = 0.01, *p* = 0.93, η^2 = 0.00.

Table 5

Thoughts Listed by Participants in Thought-suppression and Control Conditions

	Control	Thought-suppression	*t*	*p*
# Thoughts Listed	33.88 ± 23.77	32.38 ± 24.88	.54	0.60

White bear intrusions. Previous research on thought suppression has revealed that, paradoxically, attempts to supress a forbidden thought, tends to stimulate the occurrence of that thought (Mitchell et al., 2007; Wegner, 1994; Wegner & Erber, 1992). Consistent with those effects, the experimental condition resulted in 7.13 ± 5.15 (range = 1-21) reports of white bear thoughts whereas there were no thoughts of a white bear reported in the control condition (0 ± 0). This effect was evaluated using a paired-samples *t*-test, which approached significance, *t*(15) = -1.70, *p* = 0.11, *d* = 0.42.

Mental fatigue. Scores for self-reported mental fatigue are presented, by condition, in Figure 1. A 2 (condition) X 2 (time; pre-post) mixed-ANOVA was computed using condition order as a between-subjects factor. The main effect of condition was not significant, *F*(1,14) = 1.00, *p* = 0.33, η^2 = 0.07. The main effect of order, *F*(1,14) = 0.48, *p* = 0.50, η^2 = 0.03, and the condition X order interaction, *F*(1,14) = 0.21, *p* = 0.66, η^2 = 0.01, were also not significant.

However, there was a significant main effect for time, with ratings increasing following cognitive tasks, $F(1,14) = 5.22$, $p = 0.04$, $\eta^2 = 0.27$, as well as a significant time X condition interaction showing the main effect for time was driven by an increase in mental fatigue following the experimental task compared to the control task, which did not change, $F(1,14) = 4.89$, $p = 0.04$, $\eta^2 = 0.26$.

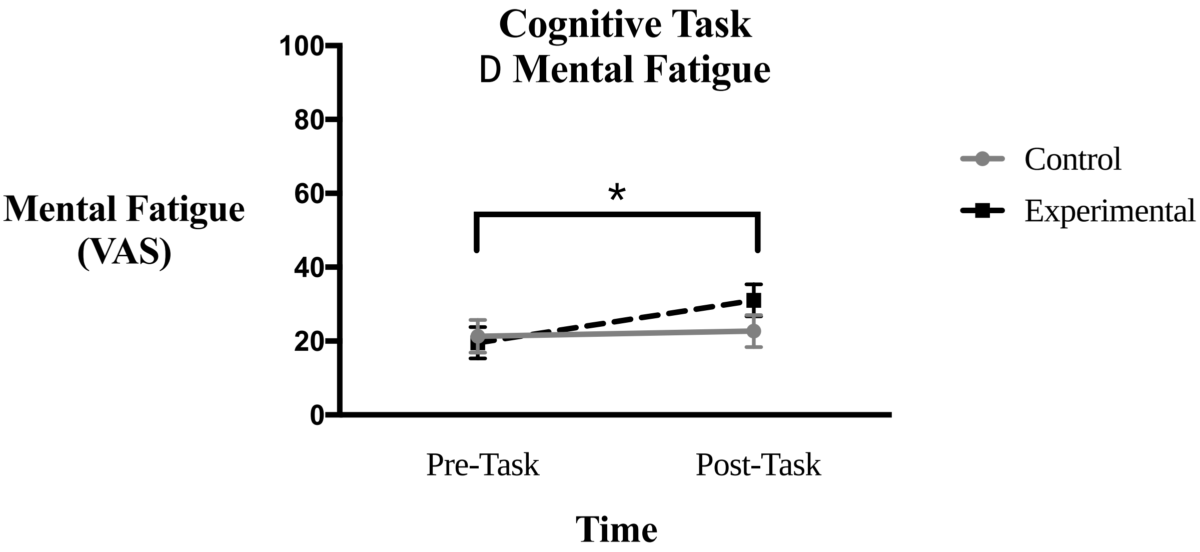

Figure 1. Ratings of mental fatigue via visual analog scale (VAS) prior-to, and following both control and experimental cognitive tasks. Ratings on the VAS can range from 0-10. Significance was attained for the main effect of time, $F(1,14) = 5.22$, $p = 0.04$, $\eta^2 = 0.27$, and a time X condition interaction, $F(1,14) = 4.89$, $p = 0.04$, $\eta^2 = 0.26$.

NASA Task Load Index (NASA TLX). Scores for three of the items comprising the NASA TLX are reported in Table 6**.** Results of the paired *t*-tests indicated that: Mental, $t(15) = -2.50$, $p = 0.02$, $d = 0.62$; Performance, $t(15) = -2.81$, $p = 0.01$, $d = 0.61$; and Effort demands, $t(15) = -3.20$, $p = 0.01$, $d = 0.79$; were perceived to be significantly higher following the experimental task compared to the control task.

Table 6

NASA Task Load Index Scores

	Control	Experimental
	M ± *SD*	*M* ± *SD*
Mental	4.63 ± 4.08	7.60 ± 4.46
Performance	4.88 ± 3.50	7.88 ± 4.00
Effort	4.88 ± 4.71	8.44 ± 4.74

Mental fatigue and task difficulty. In order to evaluate the relationships between mental fatigue, cognitive load and task difficulty, bivariate correlations were computed. These data are presented in Table 7. Net thought intrusions correlated significantly with the proportion of intrusions relative to all thoughts, $p < 0.01$. Both variables were also significantly correlated with subjective ratings of the performance demands during the experimental manipulation, $p < 0.01$. Changes in subjective mental fatigue were not significantly associated with any cognitive task measures.

Table 7

Descriptive Statistics and Bi-variate Correlations between Cognitive Task Manipulation Measures, Mental Fatigue, and NASA TLX Indices.

Variable	*M*	*SD*	1	2	3	4	5	6
1. Thought Intrusions (RAW)	7.13	5.15	-	0.88*	0.20	-0.20	0.74*	0.33
2. Thought Intrusion Proportion (WB's/All Thoughts)	0.21	0.14	0.88*	-	0.37	-0.23	0.76*	0.19
3. Δ Mental Fatigue VAS (Pre-Post)	1.15	1.76	0.20	0.37	-	0.03	0.39	-0.31
4. NASA TLX - Mental	7.59	4.46	-0.20	-0.23	0.03	-	-0.13	0.31
5. NASA TLX - Performance	7.88	4.01	0.74*	0.76*	0.39	-0.13	-	0.46
6. NASA TLX - Effort	8.44	4.74	0.33	0.19	-0.31	0.31	0.46	-

Note. * $p < 0.01$.

Preliminary Analyses (evaluating order effects)

Distance Travelled. The mixed-ANOVA with order modeled as a between-subjects factor yielded no main effect of order on distance travelled in the MDT, F (1, 14) = 0.00, p = 0.95, η^2 = 0.00. The condition X order interaction was also non-significant, F (1, 14) = 1.82, p = 0.20, η^2 = 0.12 (Table 7a).

RPE-L. A mixed-ANOVA with order accounted for as a between-subjects factor yielded no main effect of order on RPE-L in the MDT, F (1, 14) = 0.39, p = 0.54, η^2 = 0.03. The condition X order interaction was also non-significant for RPE-L, F (1, 14) = 0.01, p = 0.93, η^2 = 0.00 (Table 7b). These effects were further corroborated by comparing mean differences of RPE-L between conditions, as expressed in Table 8.

RPE-R. A mixed-ANOVA with order accounted for as a between-subjects factor yielded no main effect of order on RPE-R in the MDT, F (1, 14) = 0.03, p = 0.86, η^2 = 0.00. The condition X order interaction was also non-significant for RPE-R, F (1, 14) = 1.30, p = 0.27, η^2 = 0.09 (Table 7c). These effects were further corroborated by comparing mean differences of RPE-R between conditions, as expressed in Table 8.

RPE-M. A mixed-ANOVA with order accounted for as a between-subjects factor yielded no main effect of order on RPE-M in the MDT, F (1, 14) = 0.03, p = 0.86, η^2 = 0.00. The condition X order interaction was also non-significant for RPE-M, F (1, 14) = 0.37, p = 0.55, η^2 = 0.03 (Table 7d). These effects were further corroborated by comparing mean differences of RPE-M between conditions, as expressed in Table 8.

HR. A mixed-ANOVA with order accounted for as a between-subjects factor yielded no main effect of order on HR in the MDT, F (1, 14) = 0.49, p = 0. 50, η^2 = 0.03. The condition X order interaction was significant with HR being marginally lower at the initiation of the cycling trial following the experimental manipulation, *F* (1, 14) = 8.40, *p* = 0.01, η^2 = 0.37 (Table 7e). These effects were further corroborated by comparing mean differences of HR between conditions, as expressed in Table 8.

Cycling Workload. A mixed-ANOVA with order accounted for as a between-subjects factor yielded no main effect of order on selected workload during the MDT, *F* (1, 14) = 0.00, *p* = 0.99, η^2 = 0.00. The condition X order interaction was also non-significant for selected workload, *F* (1, 14) = 0.35, *p* = 0.57, η^2 = 0.02 (Table 7f). These effects were further corroborated by comparing mean differences of selected workload between conditions, as expressed in Table 8.

Cycling RPM. A mixed-ANOVA with order accounted for as a between-subjects factor yielded no main effect of order on selected leg speed (RPM) during the MDT, *F* (1, 14) = 0.31, *p* = 0.59, η^2 = 0.02. The condition X order interaction was also non-significant for RPM, *F* (1, 14) = 2.16, *p* = 0.16, η^2 = 0.13 (Table 7g). These effects were further corroborated by comparing mean differences of selected RPM between conditions, as expressed in Table 8.

Table 8

Summary of Statistical Tests for Order Effects and Order X Condition Interactions for Minute-Minute Data

Variable	Effect	*df*	*F*	η^2	*p*
A. Distance Travelled	Order	1, 14	0.00	0.00	0.95
	Order X Condition	1, 14	1.82	0.12	0.20
B. RPE-L	Order	1, 14	0.39	0.03	0.54
	Order X Condition	1, 14	0.01	0.00	0.93
C. RPE-R	Order	1, 14	0.03	0.00	0.86
	Order X Condition	1, 14	1.30	0.09	0.27
D. RPE-M	Order	1, 14	0.03	0.00	0.86
	Order X Condition	1, 14	0.37	0.03	0.55
E. HR	Order	1, 14	0.49	0.03	0.50
	Order X Condition	1, 14	8.40	0.37	0.01*
F. Workload	Order	1, 14	0.00	0.00	0.99
	Order X Condition	1, 14	0.35	0.02	0.57
G. RPM	Order	1, 14	0.31	0.02	0.59
	Order X Condition	1, 14	2.16	0.13	0.16

Note. Leg-muscle RPE (RPE-L), Respiration RPE (RPE-R), Mental RPE (RPE-M), Heart rate (HR). Rotations per minute (RPM).

Table 9

Summary of Statistical Tests for Order Effects and Order X Condition Interactions for Mean Data

Variable	Effect	*df*	*F*	η^2	*p*
A. RPE-L	Order	1, 14	0.39	0.03	0.54
	Order X Condition	1, 14	0.01	0.00	0.93
B. RPE-R	Order	1, 14	0.03	0.00	0.86
	Order X Condition	1, 14	1.30	0.09	0.27
C. RPE-M	Order	1, 14	0.03	0.00	0.86
	Order X Condition	1, 14	0.37	0.03	0.55
E. HR	Order	1, 14	0.49	0.03	0.50
	Order X Condition	1, 14	8.40	0.37	0.01*
F. Workload	Order	1, 14	0.00	0.00	0.99
	Order X Condition	1, 14	0.14	0.01	0.71
E. RPM	Order	1, 14	0.29	0.02	0.60
	Order X Condition	1, 14	2.75	0.16	0.12

Note. Leg-muscle RPE (RPE-L), Respiration RPE (RPE-R), Mental RPE (RPE-M), Heart rate (HR). Rotations per minute (RPM).

Main Analyses

Distance Travelled. MDT performance results are illustrated in Figure 2a**.** A 2 (condition) repeated-measures ANOVA comparing distances travelled in control (M = 10.69 ± 2.94 km; range = 5.44 – 15.42 km) and experimental (M = 10.66 ± 2.71 km; range = 5.98 – 14.95 km) trials revealed a non-significant effect, F (1, 15) = 0.05, p = 0.84, η^2 = 0.00.

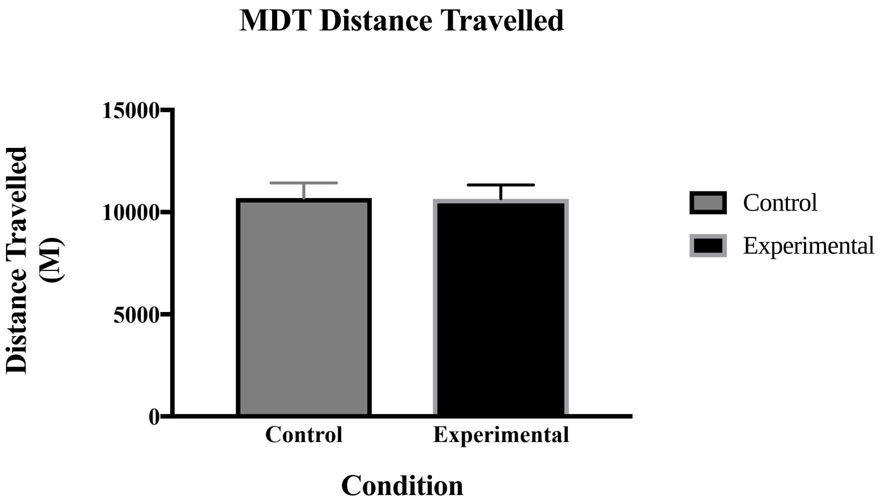

Figure 2a. Distances travelled (M = metres) by participants in experimental and control conditions were not significantly different.

To further illustrate participants' individual performances on the two MDT, distance travelled results are presented as intersecting points on an XY plot in Figure 2b**.** In this figure, points falling on the transverse diagonal represented equivalent distances travelled in control and experimental conditions. Points above the line represent greater distances travelled during the experimental trial, while points below indicating greater distance during the control trial. The figure supports the similarity of distance travelled between conditions as over half of the participants (9/16) fall directly on the transverse diagonal, indicating equal performance between conditions. 3/16 participants travelled further during control trials, while 4/16 participants travelled further during experimental trials.

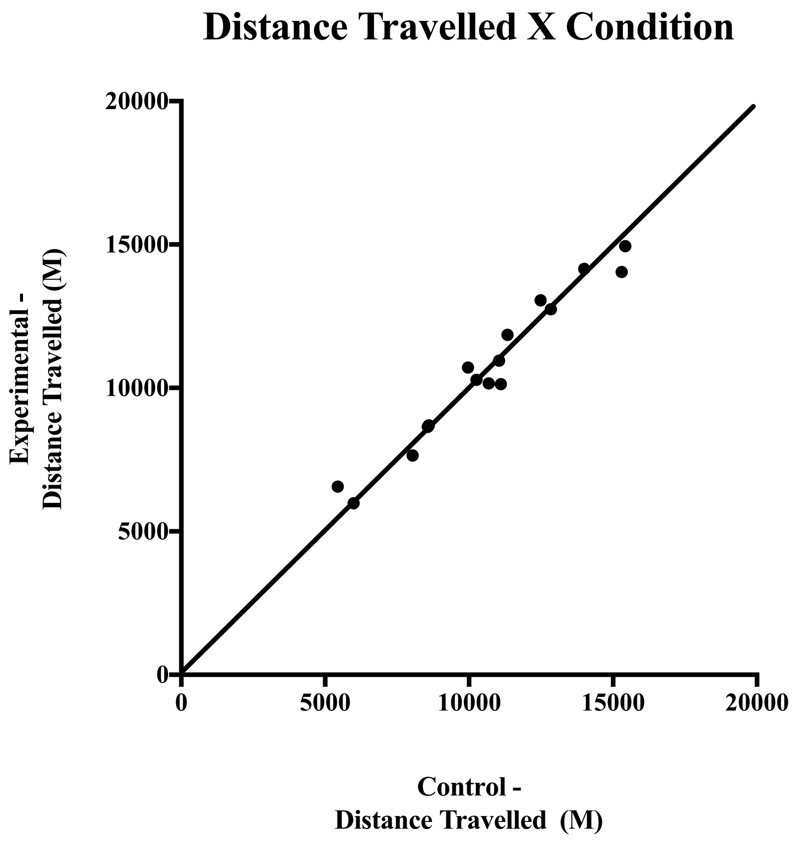

Figure 2b. Distance travelled (M = metres) in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

Workload. Results illustrating average workload during experimental and control trials are illustrated in Figure 3a. An initial paired samples t-test showed no significant difference in average workload between the control and experimental trials, $t\ (15) = 0.32$, $p = 0.76$, $d = 0.08$.

In order to examine the patterns of selected workload between conditions, average loads were plotted over time using 1-minute interval data. These data are expressed in Figure 3b**.** A 2 (condition) X 20 (time) repeated measures ANOVA resulted in a significant main effect of time $F\ (2.47, 37.06) = 8.95$, $p < 0.01$, $\eta^2 = 0.37$, with workload generally increasing as a function of time elapsed in the MDT. The main effect of condition was not significant $F\ (1, 15) = 0.28$, $p = 0.61$, $\eta^2 = 0.02$. The condition X time interaction was also non-significant, $F\ (3.82, 57.26) = 1.18$, $p = 0.33$, $\eta^2 = 0.07$.

As a qualitative analysis of sessional workload selections, individual average wattages for control and experimental MDT trial are graphed on an intersecting XY plot in Figure 3c**.** In this figure, points that are found on the transverse diagonal line represent equivalent ratings in both conditions. 7/16 data points are found along the transverse diagonal, pointing to similar workload selections during the MDT, regardless of condition. 5/16 individuals selected marginally greater loads during control trials, as evidenced by falling below the transverse diagonal. 4/16 individuals fell slightly above the line, indicating greater loads selected in experimental trials.

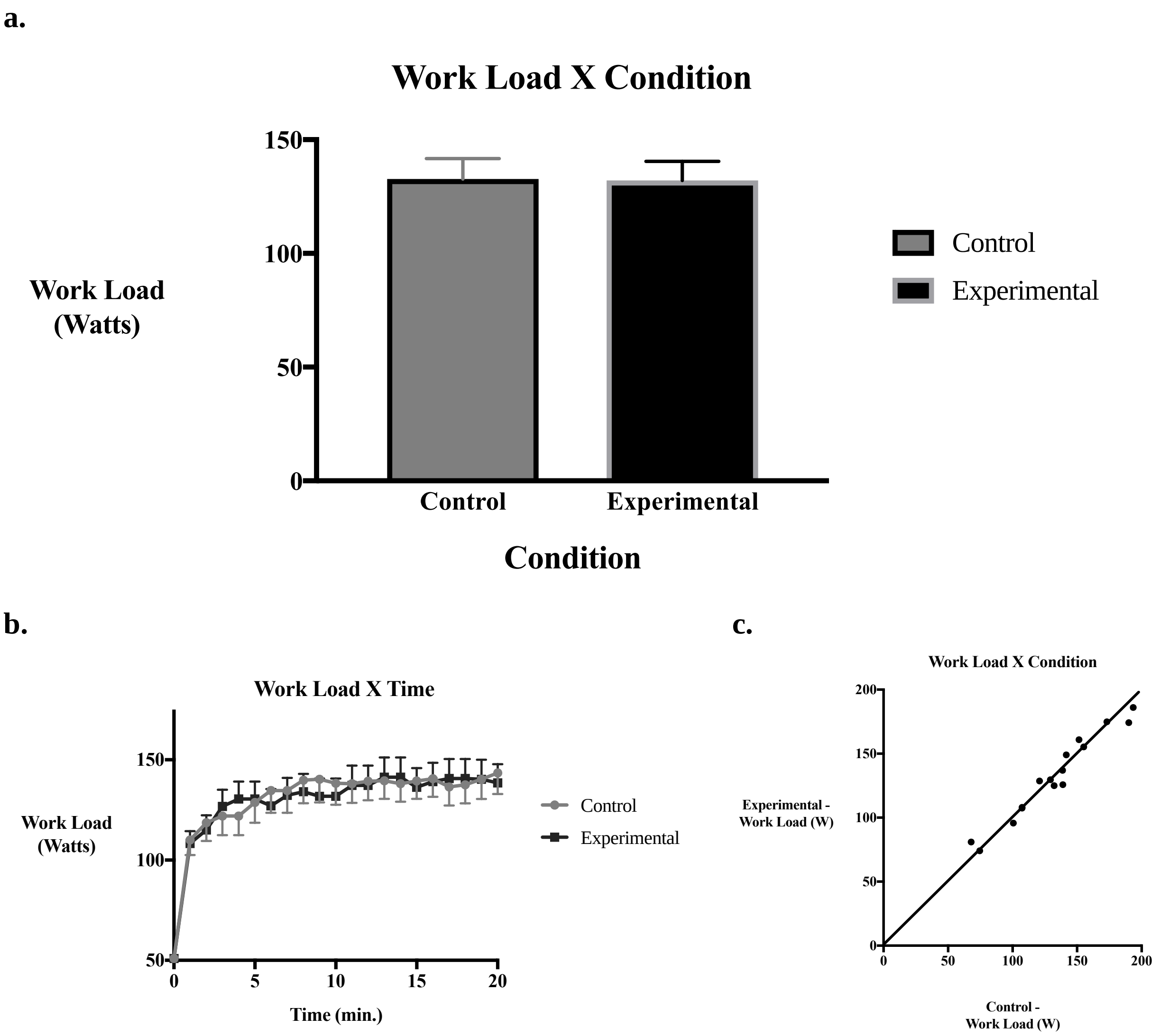

Figure 3. 3a: Illustration of mean workloads selected by participants in experimental and control conditions. 3b: Illustration of minute-by-minute workload during the MDT. 3c: Mean workload selected in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

RPM. Results illustrating average leg speed (RPM) during experimental and control trials are illustrated in Figure 4a. An initial paired samples t-test showed no significant difference in average workload between the control and experimental trials, t (15) = 0.43, $p = 0.67$, $d = 0.11$.

In order to examine the patterns of leg speed between conditions, average RPMs were plotted over time using 1-minute interval data. These data are expressed in Figure 4b**.** A 2 (condition) X 20 (time) repeated measures ANOVA resulted in a significant main effect of time F (3.82, 57.36) = 5.33, $p < 0.01$, $\eta^2 = 0.26$, with RPM increasing slightly as a function of time elapsed in the MDT. The main effect of condition was not significant F (1, 15) = 0.28, $p = 0.60$, $\eta^2 = 0.02$. The condition X time interaction was also non-significant, F (4.99, 74.87) = 0.94, $p = 0.46$, $\eta^2 = 0.06$.

Individual average RPMs are plotted on an intersecting XY plot for control experimental conditions in Figure 4c. In this figure, points that are found on the transverse diagonal line represent equivalent ratings in both conditions. 5/16 data points are found along the transverse diagonal, pointing to similar mean leg speed during the MDT, regardless of condition. 7/16 individuals pedalled marginally faster during control trials, as evidenced by falling below the transverse diagonal. 4/16 individuals fell slightly above the line, indicating faster leg speeds in experimental trials.

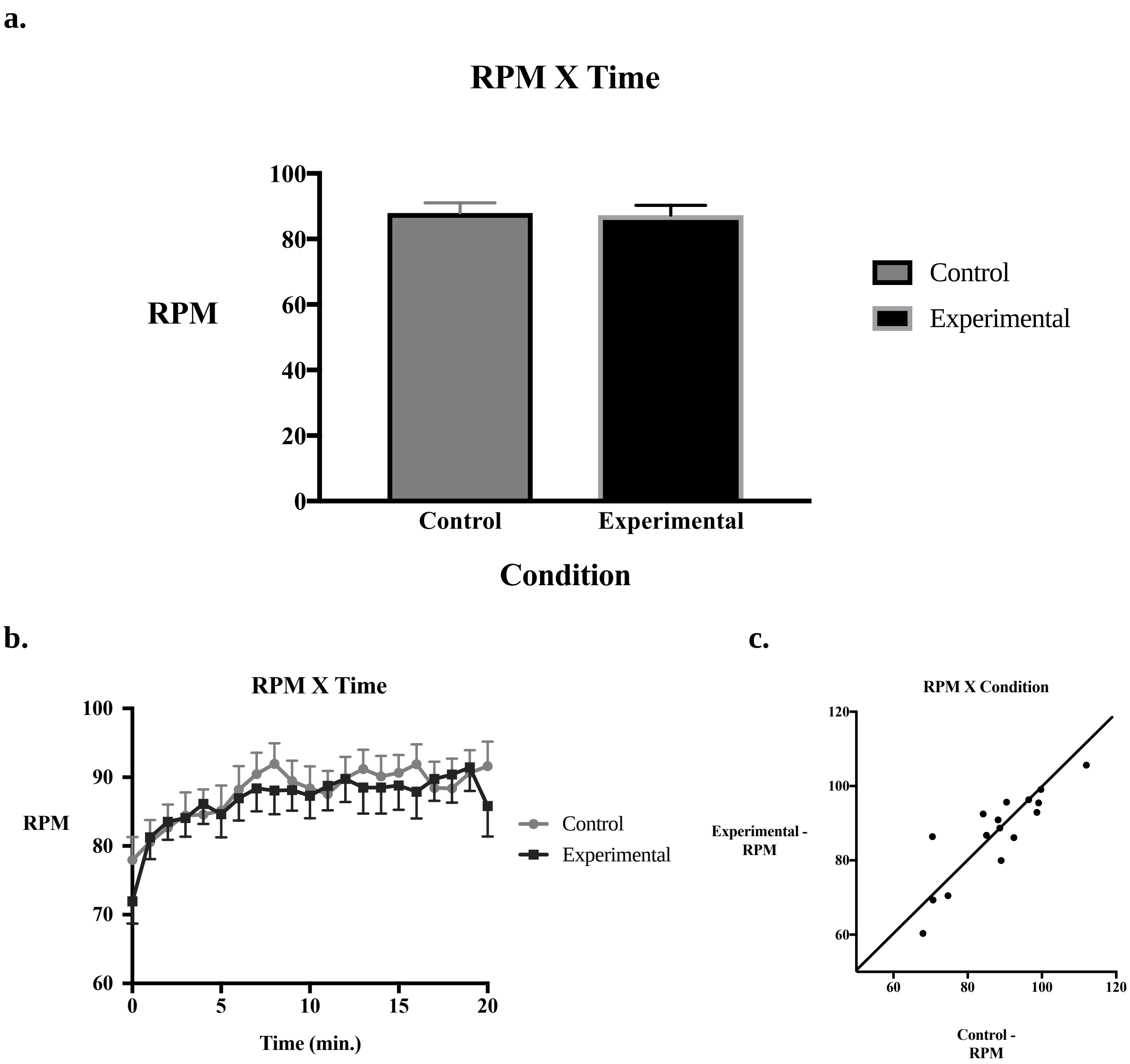

Figure 4. 4a: Illustration of mean leg-speeds (RPM) selected by participants in experimental and control conditions. 4b: Illustration of minute-by-minute RPM during the MDT. 4c: Mean RPM selected in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

HR. Results illustrating average HR during experimental and control trials are illustrated in Figure 5a. An initial paired samples t-test showed no significant difference in average HR between the control and experimental trials, t (15) = 0.08, p = 0.94, d = 0.02.

To explore the patterns of HR between the two conditions, condition means were plotted over time using 30-sec interval data. These data are expressed in Figure 5b**.** A 2 (condition) X 40 (time) repeated-measures ANOVA showed a significant main effect of time F (2.40, 35.92) = 95.50, $p < 0.001$, $\eta^2 = 0.86$, with HR increasing as a function of time elapsed in the MDT. The main effect of condition was not significant, F (1, 15) = 0.00, p = 0.95, $\eta^2 = 0.00$. The condition X time interaction was also not significant, F (3.845 51.79) = 0.82, p = 0.50, $\eta^2 = 0.05$.

As a means of contrasting sessional HR between conditions, individual averages for each trial are graphed on an intersecting XY plot in Figure 5c**.** In this figure, points that are found on the transverse diagonal line represent equivalent ratings in both conditions. All 16 data points are found along the transverse diagonal, pointing to similar physiological responses to the MDT regardless of condition.

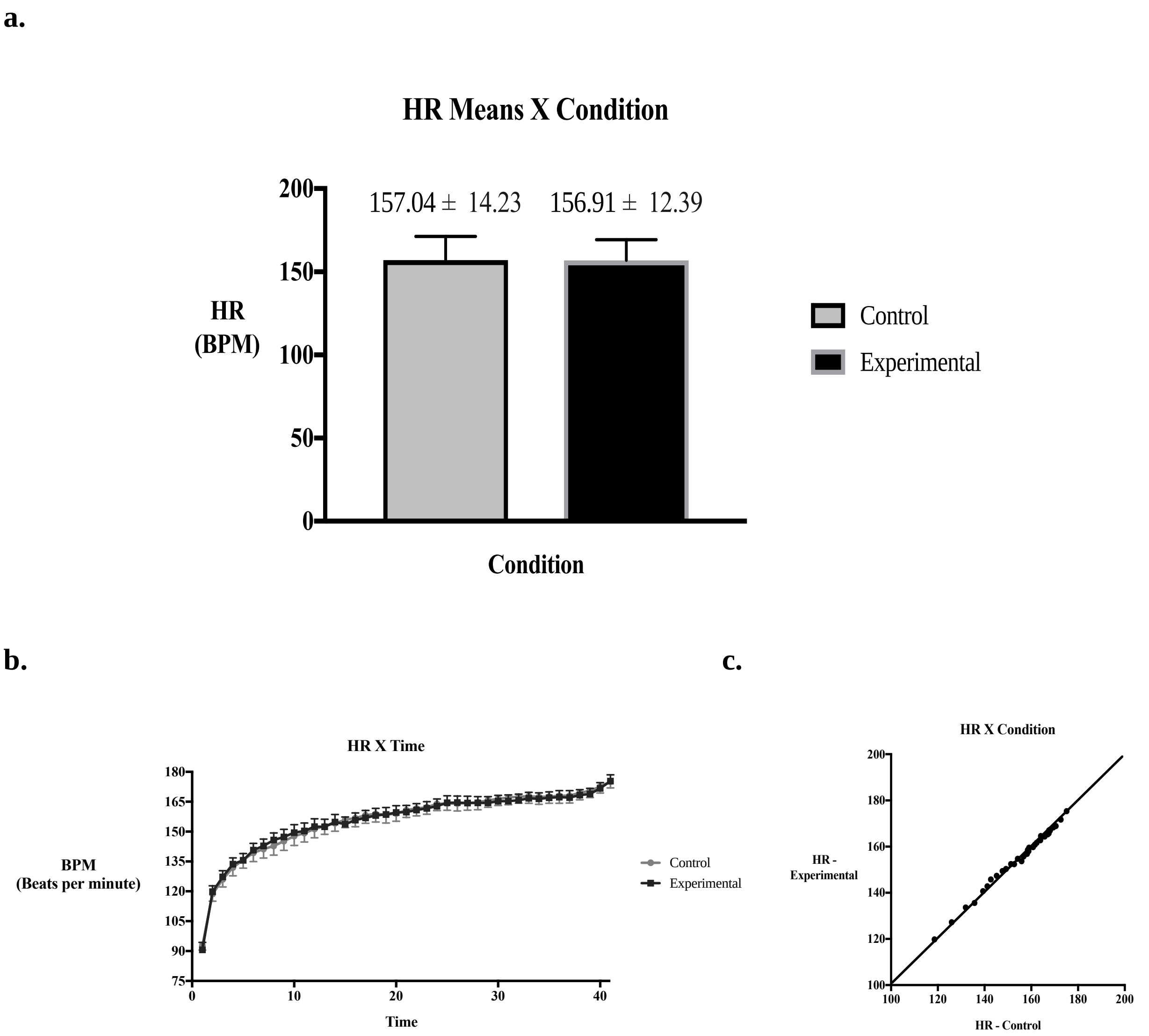

Figure 5. 5a: Illustration of mean heart rates (HR) in experimental and control conditions. 5b: Illustration of minute-by-minute HR during the MDT. 5c: Mean HR in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

RPE-L. Results illustrating average RPE-L during experimental and control trials are displayed in Figure 6a. An initial paired samples *t*-test showed a significant difference in average RPE-L between the control and experimental trials, t (15) = -2.16, $p = 0.05$, $d = 0.55$, with greater RPE-L in the experimental condition. A bootstrapped model accounting for 1000 samples and a 95% confidence interval verified the observed difference between control and experimental conditions was significant, t (15) = -2.16, $p = 0.05$, $d = 0.55$, 95% CI [-0.54, -0.05].

To further probe the significant effect of condition on the average RPE-L scores, and patterns of RPE-L in the two conditions, RPE-L was plotted, by condition and over time using 1-min interval data in Figure 6b. The 2 (condition) X 20 (time) repeated-measures ANOVA showed a significant main effect of condition F (1, 15) = 4.68, $p = 0.05$, $\eta^2 = 0.24$, with higher ratings consistently reported in the experimental condition throughout the trials. There was also a significant main effect of time whereby ratings of exertion increased in both conditions throughout the course of the MDT, F (1.66, 24.86) = 42.01, $p < 0.001$, $\eta^2 = 0.74$. However, the condition X time interaction was not significant, F (3.88, 58.15) = 0.34, $p = 0.84$, $\eta^2 = 0.02$.

To further illustrate participants' RPE-L in the control and experimental conditions, individual average RPE-L scores for each trial are presented as intersecting points on an XY plot in Figure 6c**.** In this figure, points falling on the transverse diagonal represent equivalent ratings in both conditions. Points falling above the line represent higher RPE-L during the experimental trial and points below represent higher ratings in the control trial. In this case, 9/16 reported higher RPE-L in the experimental trial. As evidenced by falling on the transverse diagonal, 2/16 participants provided similar ratings in both trials, and 4/16 reported higher RPE-L in the control trial.

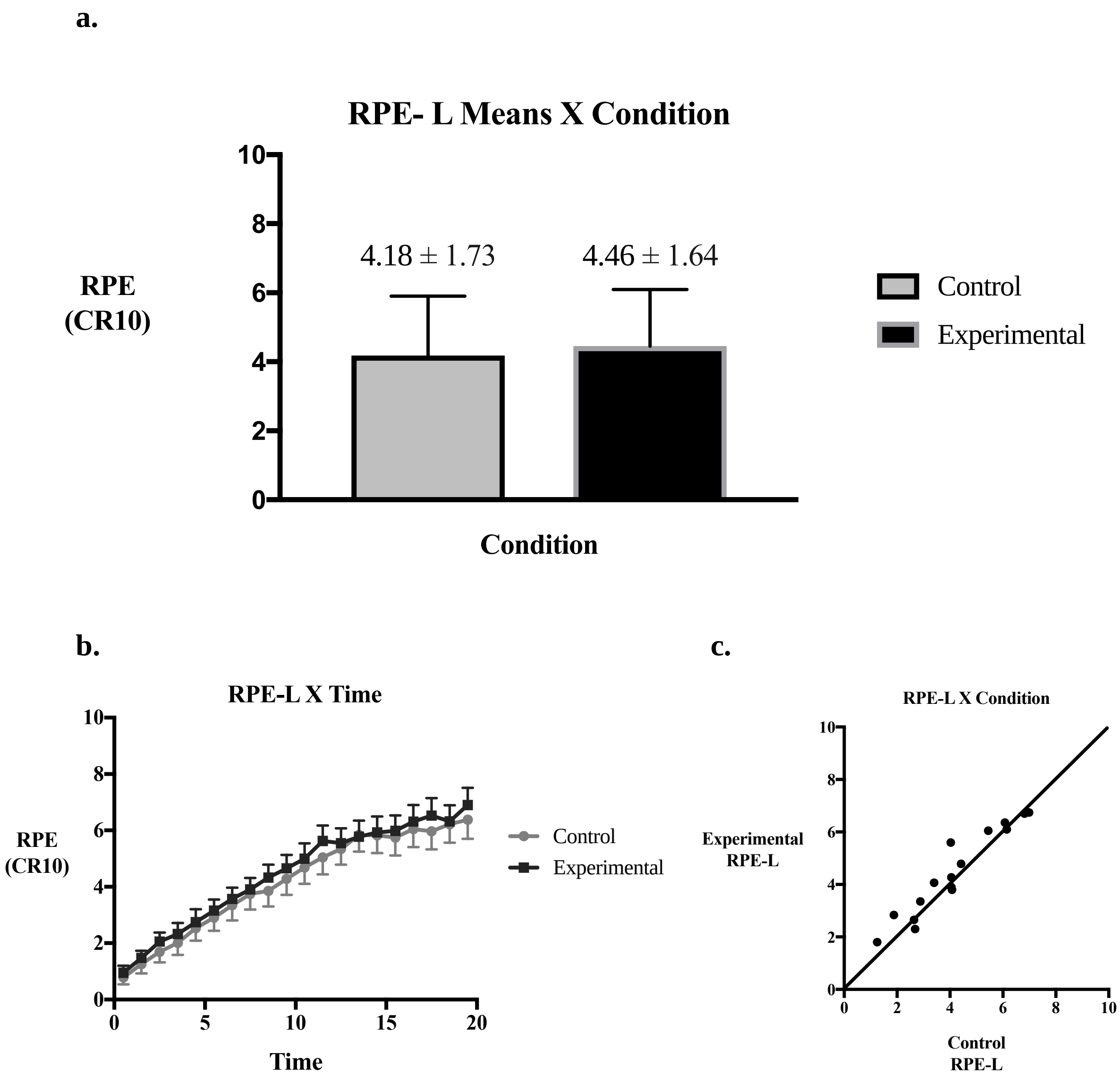

Figure 6. 6a: Illustration of mean leg-muscle ratings of perceived exertion (RPE-L) in experimental and control conditions. 6b: Illustration of minute-by-minute RPE-L during the MDT. 6c: Mean RPE-L in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

RPE-R. Average RPE-R ratings for control and experimental trials are displayed in Figure 7a. A paired-samples *t*-test determined non-significant differences between conditions, t (15) = -1.75, $p = 0.12$, $d = 0.45$. A supplemental bootstrapped model accounting for 1000 samples and a 95% confidence interval also confirmed non-significance, t (15) = -1.75, $p = 0.12$, $d = 0.45$, 95% CI [-0.72, 0.04].

Figure 7b displays RPE-R in both conditions as a function of time, with ratings displayed every minute. The 2 (condition) X 20 (time) repeated-measures ANOVA determined that the main effect of condition was non-significant, despite a visual trend towards higher RPE-R ratings during experimental trials, F (1, 15) = 3.06, $p = 0.10$, $\eta^2 = 0.17$. A significant main effect of time was observed, F (1.95, 29.21) = 39.53, $p < 0.001$, $\eta^2 = 0.73$, with ratings increasing throughout the MDT, regardless of condition. The model's condition X time interaction was non-significant, F (4.33, 64.91) = 0.55, $p = 0.71$, $\eta^2 = 0.04$.

As a further illustration contrasting control and experimental sessions, individual average RPE-R scores are presented as intersecting points on an XY plot in Figure 7c**.** As evidenced by falling on the transverse diagonal, half of the participants (8/16) participants provided similar ratings in both conditions. 6/16 participants reported higher RPE-R ratings during experimental trials, while only 2/16 reported higher ratings following the control manipulation.

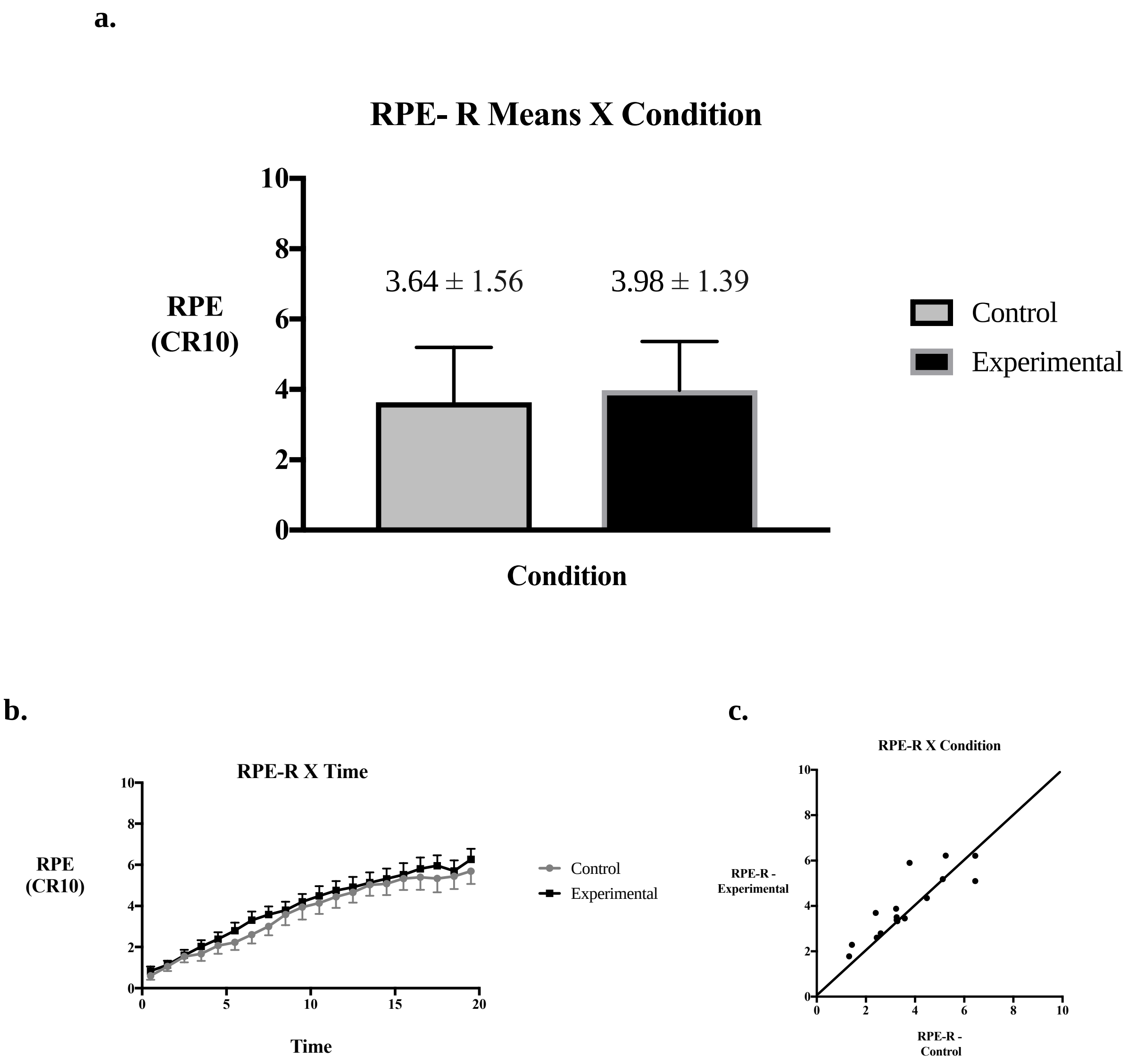

Figure 7. 7a: Illustration of mean respiration ratings of perceived exertion (RPE-R) in experimental and control conditions. 7b: Illustration of minute-by-minute RPE-R during the MDT. 7c: Mean RPE-R in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

RPE-M. Figures illustrating ratings of perceived mental exertion are found in Figure 8a. A paired-samples t-test determined a non-significant difference in average RPE-M in control and experimental trials, t (15) = -1.20, p = 0.26, d = 0.30. A bootstrapped model with 1000 samples and a 95% confidence interval, further substantiated the non-significant findings, t (15) = -1.20, p = 0.26, d = 0.30, 95% CI [-0.57, 0.10].

RPE-M is plotted as a function of condition over time, using 1-min interval data in Figure 8b. A 2 (condition) X 20 (time) repeated-measures ANOVA resulted in a non-significant main effect of condition, F (1, 15) = 1.46, p = 0.25, $\eta^2 = 0.09$. A main effect of time however, was found to be statistically significant, F (1.52, 22.81) = 23.97, $p < 0.01$, $\eta^2 = 0.62$, with ratings increasing over the course of both experimental and control MDTs. The model's condition X time interaction was determined to be statistically non-significant, F (3.37, 50.48) = 1.02, p = 0.40, $\eta^2 = 0.06$.

Once again, to further illustrate the contrast of RPE-M ratings between conditions, individual scores are presented as intersecting data points on an XY plot in Figure 8c. With the transverse diagonal representing equal ratings between conditions, approximately 7 participants provided equivalent ratings. 5/16 participants reported higher RPE-M ratings during experimental trials, 4/16 reported higher ratings following the control manipulation.

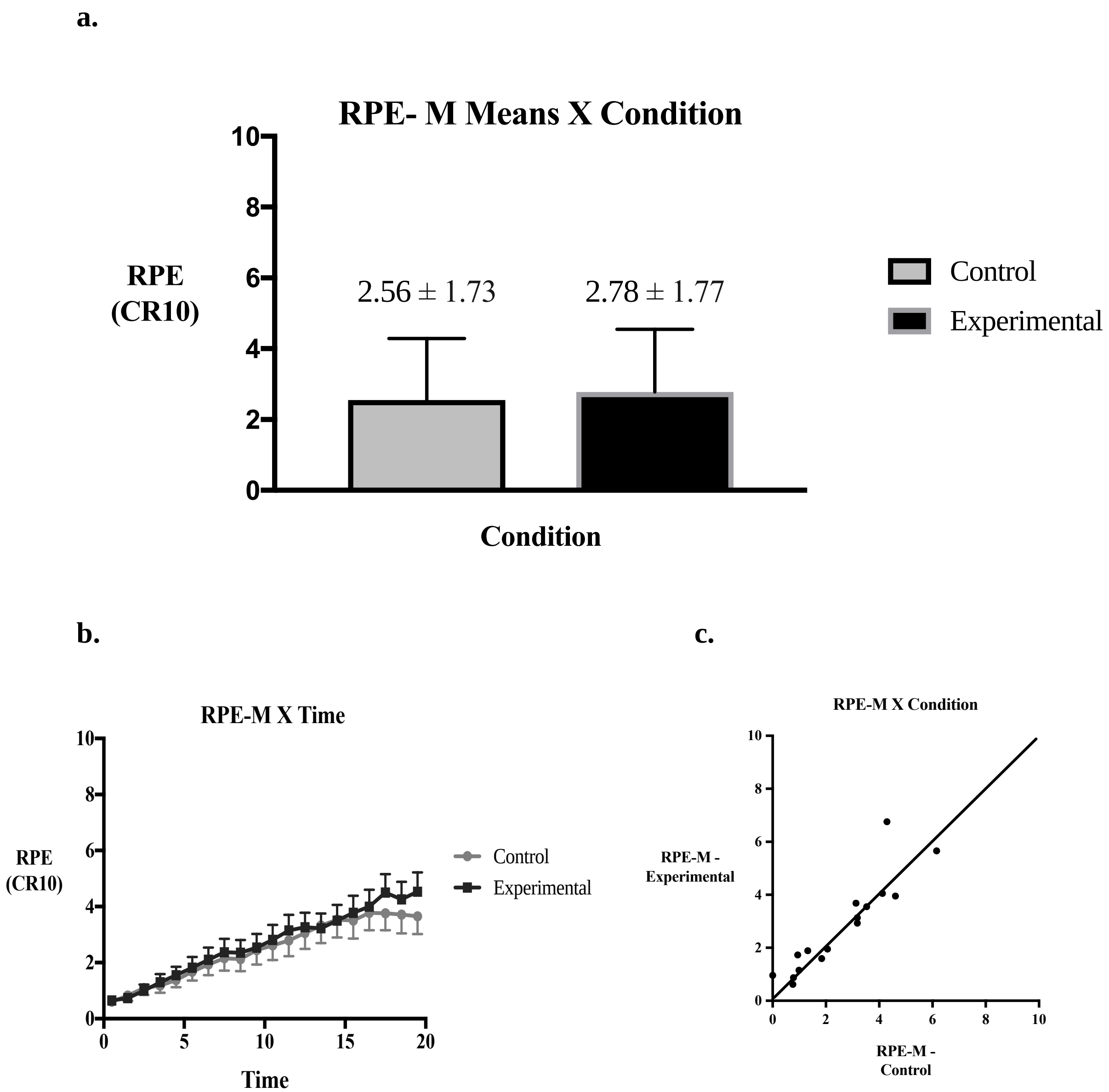

Figure 8. 8a: Illustration of mean ratings of perceived mental exertion (RPE-M) in experimental and control conditions. 8b: Illustration of minute-by-minute RPE-M during the MDT. 8c: Mean RPE-M in control and experimental trials are listed on x- and y-axes, respectively. The transverse diagonal line indicates equal performance between conditions.

Differential RPE. RPE-L, RPE-B, and RPE-M are plotted as a function of condition in Figure 9. A 2 (condition) X 3 (RPE modality) mixed ANOVA resulted in a significant main effect of condition, F (1, 15) = 4.45, $p = 0.05$, $\eta^2 = 0.23$. Generally higher ratings were elicited for all 3 dRPE modalities in experimental conditions relative to controls. A main effect of RPE modality was also found to be statistically significant, F (1.41, 32.43) = 13.10, $p < 0.01$, $\eta^2 = 0.47$, with RPE-M ratings being lower than both RPE-L and RPE-B. Additionally, in both conditions RPE-L was rated significantly higher than both remaining RPE modalities. The model's condition X RPE modality interaction was determined to be statistically non-significant, F (2, 30) = 0.17, $p = 0.84$, $\eta^2 = 0.01$.

Planned contrasts were computed to determine key differences in the model. A summary of these results is included in Table 9. RPE-M was rated significantly lower relative to RPE-L, in both experimental, t (15) = 4.58, $p < 0.01$, and control conditions, t (15) = 3.90, $p < 0.01$. RPE-M was also rated significantly lower relative to RPE-R, in both experimental, t (15) = 3.38, $p < 0.01$, and control conditions, t (15) = 2.54, $p = 0.02$. Lastly, RPE-L was perceived to be significantly higher than RPE-R in both experimental, t (15) = 2.31, $p = 0.04$, and control conditions, t (15) = 2.42, $p = 0.03$.

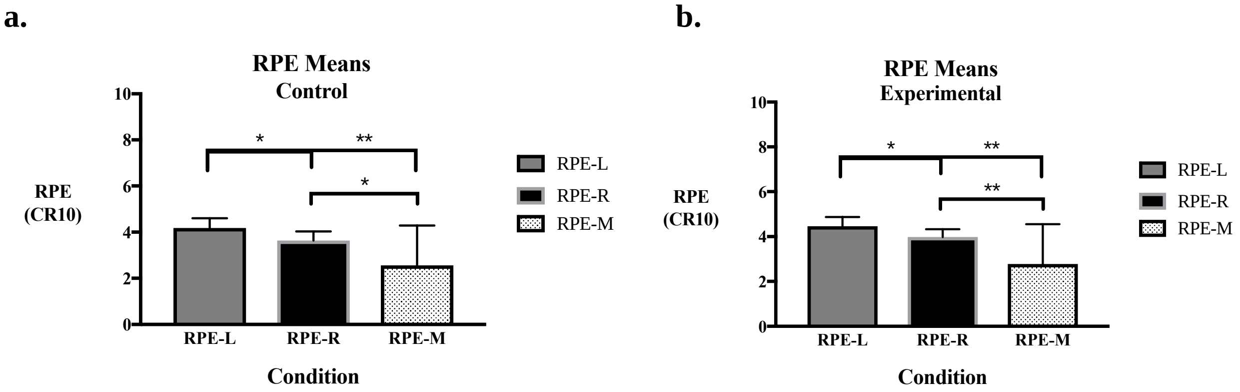

Figure 9. Figure 9a and 9b illustrate the differences in mean ratings of RPE for: leg-muscle (RPE-L), respiration (RPE-R), and mental (RPE-M), in control and experimental conditions, respectively. *$p < 0.05$, **$p < 0.01$.

Table 10

Summary of Planned Contrasts of Means for RPE Modalities

Condition	Contrast	*df*	*t*	*p*	*d*
Control	RPE-L – RPE-M	15	3.89	< 0.01	0.97
	RPE-R- RPE-M	15	2.54	0.02	0.64
	RPE-L – RPE-R	15	2.42	0.03	0.62
Experimental	RPE-L – RPE-M	15	4.58	< 0.01	1.15
	RPE-R- RPE-M	15	3.38	< 0.01	0.88
	RPE-L – RPE-R	15	2.31	0.04	0.60

Note. Leg-muscle exertion (RPE-L). Mental exertion (RPE-M). Respiration exertion (RPE-R).

Discussion

The purpose of the present study was to examine the impact of thought suppression on differential ratings of perceived exertion as well as performances on a self-paced, whole-body endurance exercise task. The white bear thought suppression manipulation was associated with small but significant increases in mental fatigue compared to a thought-logging control task. Contrary to the findings of several prior studies, participants did not suffer performance losses on the self-paced maximum-distance cycling trial (MDT) in the mental fatigue condition. However, consistent with the primary hypothesis, participants reported significantly higher ratings of perceived leg-muscle exertion (RPE-L) while exercising following the experimental task, relative to the control task. Although the effects were not significant at the $p < .05$ level, perceived respiratory (RPE-R) and mental exertion (RPE-M) also resulted in small-medium sized effects, with higher ratings reported during the exercise bout that followed the thought suppression task. Heart rate patterns were consistent between conditions, indicating similar physiological responses to the exercise task regardless of mental fatigue levels.

Distance Travelled

Based on a comprehensive review of the literature, it was hypothesized that there would be an interaction between exercise performance and RPE as a consequence of mental fatigue. One possibility was that participants would travel less distance in the self-paced cardiovascular exercise task following the mentally-fatiguing cognitive self-control manipulation, relative to controls. However, no significant differences were observed between conditions and, indeed, the distance travelled in each trial was nearly identical over 20-minutes, with both conditions averaging over 10-km covered. Many studies have reported deleterious effects on endurance exercise performance following bouts of mentally-fatiguing tasks (MacMahon et al., 2014;

Marcora et al., 2009; Pageaux, Lepers, Dietz & Marcora, 2014; Zering et al., 2017). Yet, several studies have also found similar performances in whole-body exercises following both control and mentally-fatiguing tasks (Duncan, Fowler, George, Joyce & Hankey, 2014; Martin et al., 2015; Smith, Marcora & Coutts; 2015; Pageaux, Marcora, Rozand & Lepers, 2015).

One possible mechanism that could explain why performance is similar in some tasks vs. others is that some tasks have fixed workload demands, while others offer flexibility for the participant to adjust the workload. Because the workload during the task in the present study was self-determined, it is possible that participants may have applied different pacing strategies during the two trials, which prompted a more fine-grained analysis of participants' behaviour during the cycling tasks to be undertaken. Specifically, to address this issue, minute-by-minute data of objective workloads as well as pedalled revolutions per minute (RPM) during the MDT were compared between the control and experimental trials. Results, shown in Figure 3 and 4 show that both metrics of behaviour were virtually identical in each exercise trial. One way in which these results are interesting, relates to previous research that has shown that self-control depletion manipulations cause people's perceptions of time to elongate (i.e., time feels like it is taking longer to pass when one is depleted of self-control strength; Vohs & Schmeichel, 2003). However, participants in the present study were given access to a countdown timer while they cycled, which may have mitigated the time-elongation effect. Had there not been a timer, it may have been predicted that participants' pacing strategies would have been altered as they would have had only their "internal clock" to go by when determining their pedaling speeds and workloads.

Cycling performance and behaviour were nearly identical during the MDT cycling tasks, consequently it is not surprising there were no differences observed between conditions when comparing average HRs (Figure 5a), or when comparing 30-second interval data expressed in Figure 5b. Marcora and colleagues (2009) noted specifically that physiological measures such as cardiac output, oxygen consumption, blood lactate, and HR, all showed no effect of mental fatigue. These findings remained true when significant and large decrements in physical performance were observed (Marcora et al., 2009). The present findings support the idea that mental fatigue may not impact fundamental physiological responses such as increases in heart rate elicited by demanding physical activity, as these may be primarily determined by the body's homeostatic response to exercise (Marcora et al., 2009; Martin et al., 2015; Pageaux et al., 2013).

Although there were no differences between the exercise trials in cycling performance, participants reported higher ratings of perceived exertion during the MDT after completing the thought-suppression task. These results were predicted and align with Van Cutsem et al.'s (2017) review suggesting RPE may be an important indicator of common psychophysiological processes that underpin mental and physical fatigue. However, the present study ads to the extant literature by implementing a dRPE methodology and distinct trends emerged for the three perceived exertion modalities being investigated.

Leg-muscle exertion (RPE-L) served as the study’s primary measure of peripheral exertion during the exercise task. Successful cycling performance is theorized to be largely contingent on leg-muscle performance (McLaren et al., 2017). Therefore, it was hypothesized that RPE-L would be significantly higher on the cycling task when mentally fatigued, relative to non-fatigued control trials. As hypothesized, significant differences emerged in participants’ ratings of leg muscle exertion between conditions, with a medium effect size (*d* = 0.55). Examination of the minute-by-minute trends in RPE-L in Figure 6, shows participants rated RPE-L higher from the initiation of the cycling task following thought suppression and this trend persisted throughout the entire 20-minute endurance task. Moreover, as McLaren and colleagues (2017) noted – dRPE typically increases linearly when the dRPE modalities in question more closely match the demands of the physical task. In this case, participants' ratings of RPE-L were objectively higher than other modalities (RPE-R, RPE-M), increased linearly in both conditions over the course of the 20-minute trials, and ended close to maximum at the end of each trial. In these regards, the findings are consistent with the results reported by Marcora and colleagues (2009), where holistic ratings of perceived exertion were higher when exercising following 90-minutes of mentally-fatiguing cognitive activity compared to the control condition, with both exercise trials ending with maximal RPE.

While RPE-L provided information regarding participants' local, or peripheral, sense of effort, respiration exertion (RPE-R) was prompted from participants as an assessment of exertion levels pertaining to sensations more central in origin. It is important to note that the term "central" used for RPE relates to the cardiopulmonary sensations and not those of the central nervous system (Ekblom & Goldbarg, 1971). For this central sensation, participants were asked to rate RPE-R based on their breathing rate, depth and quality. The statistical evaluation of the differences between conditions was non-significant, yet differences in RPE-R were in the expected direction (i.e., higher) when participants were mentally-fatigued with a small-medium effect, relative to control trials ($d = 0.45$). These findings are consistent with a recent study by Borg, Borg, Larsson, Letzter and Sundblad (2010), where ratings of leg muscle exertion were a dominant perception over "breathlessness" and interpreted as the more potent limiting factor of strenuous exercise. Along these lines, the present findings also suggest that mental fatigue may serve to heighten the sensation of RPE that is the most recognizable to participants for the activity they are performing (i.e., RPE-L). Investigating the effects of mental fatigue on RPE while performing exercise under conditions that challenge breathlessness (e.g., hypoxia) could reveal stronger effects on RPE-R and would be an interesting avenue of future research.

It was predicted that ratings of perceived mental exertion (RPE-M) would be higher while performing the exercise task after completing the thought-suppression task. Contrary to the hypothesis, differences in RPE-M were not statistically significant over the course of the 20-minute cycling task. However, there was a small effect of condition, with marginally higher ratings being elicited during the exercise task when participants were mentally-fatigued ($d = 0.30$). It is also interesting to note the trend evident when visually assessing the plot for RPE-M in Figure 8. That is, in both conditions, RPE-M increased with identical progressions for the first seventeen minutes of the bout. In the final three-minutes however, there was a marked deviation in the mental-fatigue condition where participants reported significantly higher ($p < .05$) ratings (i.e., independent t-tests at those time-points), relative to the control condition. Further, in the non-fatigue condition, participants rated the final three-minutes as “Somewhat Hard” on the RPE-M scale, while in the fatigue condition they rated RPE-M as "Hard", despite there being no differences in workload or RPM at that point in the exercise test. RPE-M may provide unique insights into people's sensory experiences when they exercise as it represents exertion that is experienced in the central nervous system. The anecdotal observation that RPE-M was greater when participants engaging in an all-out "end spurts" for the MDT suggests again that, when they are mentally fatigued, peoples' sensory experiences may become hypersensitive to symptoms that are most closely linked to the demands of the task. In this case, RPE-M was no different when participants were maintaining a steady pace through most of the MDT, but when they were bearing down at the end of task with their strongest effort to gain the most distance possible, they rated their mental exertion much higher after having been mentally- fatigued earlier on.

Overall Insights

Potential Mechanisms

This was primarily an observational study that attempted to determine whether physical performance and psychophysiological sensations during exercise were affected by mental or self-regulatory fatigue. Thus, there is no way to evaluate any potential physiological mechanisms that could explain why RPE was greater following the mental fatigue manipulation despite equivalent physical performance. One possible explanation for the observed effects of depletion may revolve around glucose availability and more specifically the expenditure of glucose in both the body and in the brain (Gaillot & Baumeister, 2007). There have been reports of blood glucose levels being reduced following performance of cognitive tasks proposed to deplete self-control resources (Ainsworth, Baumeister & Boroshuk, 2016). However, these effects have not reliably been observed across several replication attempts (Baumeister & Vohs, 2016) and have been questioned in terms of their biological plausibility (Kurzban, 2010). Additional studies by Gaillot et al. (2007) have also found that ingestion of glucose supplements prior to engaging in tasks that require self-control can attenuate the negative effects of self-control depletion. Despite these findings, it has also been observed that merely swishing a glucose rinse in one's mouth can attenuate the deleterious effects of mild self-control depletion (Gaillot, Baumeister, et al., 2007), which also raises questions about the essential role of glucose depletion or availability. Baumeister and Vohs (2016) concluded that although more research is needed, a resource allocation account of systemic glucose fits within the current iteration of the strength model of self-control.

Another explanation comes from studies that have looked at neural substrates in attempts to understand the origins of the sense of effort. Central to this line of reasoning is the idea that mental fatigue affects the central processing of individuals' discrete sensory inputs, ultimately generating a higher perception of effort during physical performance. There is evidence to suggest that mental fatigue may be associated with activation levels in cortical structures involved in the cognitive components of central motor command (Hallett, 2007). A specific region of the brain known as the anterior cingulate cortex (ACC) is often cited as a cortical area responsible for self-regulatory functions like emotion, homeostatic drive, and motor control (Paus, 2001). Interestingly, demanding cognitive tasks such as the AX-CPT and Stroop task have been shown to activate the ACC as well as result in reports of elevated mental fatigue (Cook, O'Connor, Lange, Steffner, 2007). Importantly, engaging in thought suppression also has been shown to increase activation of the ACC (Mitchell et al., 2007; Wyland, Kelley, Macrae, Gordon, & Heatherton, 2003).

Taken together, it appears that the sense of effort may be partially derived from activation of the ACC, which may be an instrumental aspect of central motor command necessary to complete tasks such as exhaustive exercise. In the present study, what is believed to be depleted self-control resulted in the self-paced whole-body exercise task being perceived as requiring more exertion. However, it also seems possible the initial bouts of thought suppression caused greater activation of the ACC such that subsequent motor drive invested in the cycling task was perceived to require greater exertion.

Ecologic Validity of Thought Suppression and Practical Implications

The strength model of self-control is an elegant model that postulates initial bouts of self-control exertion result in the consumption of finite resources, which ultimately lead to less ability to persist in subsequent activities demanding of self-control (Baumeister & Vohs, 2016). The majority of studies that have tested this model have utilized a paradigm (sequential task) involving experimentally-derived cognitive manipulations designed to deplete individuals of self-control resources or induce mental fatigue. As illustrated in Tables 1 and 2, computerized tasks such as; the AX-CPT, the Switch Task paradigm, as well as the Stroop Task, have all reliably demonstrated the capacity to negatively impact performance on subsequent physical tasks that also require self-control (Brown & Bray, in press; Budini, Lowery, Durbaba & Cottrell., 2014; Marcora et al., 2009; Zering et al., 2017). However, despite these tasks requiring response inhibition, working memory, or some other aspect of executive control, they are not activities that have a great deal of relevance in real-world situations. In contrast, people commonly experience unwanted thoughts in everyday situations (Wegner et al., 1987) and, depending on the situation, choose to repress such cognitions. Because unwanted thoughts often have the paradoxical tendency to persist or re-enter consciousness (Wenzlaff & Wegner, 2000) exerting control over such thoughts has been shown to require self-control and lead to ego depletion (Muraven et al., 1998).

Given the tendency for athletes to experience negative thinking and self-talk (Moran, 2012), investigation of thought suppression as a manipulation that could negatively impact physical performance has strong ecological relevance to sport. The present study is the first controlled experiment to have had participants complete a thought suppression manipulation prior to performing whole-body endurance exercise. Interestingly, six-minutes of exposure to the thought suppression manipulation was sufficient to induce feelings of mental fatigue in participants. Ultimately, this translated to significant differences in the perception of effort during subsequent exercise. These findings thus have potentially-important implications for sport performers and practitioners (e.g., coaches, sport psychologists) in so far as they indicate controlling one's thoughts can heighted feelings of mental fatigue and the exertion experienced when performing demanding whole-body exercise. Although there were no performance differences in the present study, the lingering or delayed effects of having exerted more effort may be important limiting factors in events lasting longer than 20 minutes or when athletes may compete in several sequential events in a day (e.g., tournaments).

One consideration for practitioners and athletes is to weigh the potential costs and benefits of thought suppression. Specifically, suppressing an unwanted thought may be fatiguing, however, persistent negative thoughts (e.g., catastrophizing) may have detrimental effects on emotional states. Therefore, trying to suppress those thoughts may be the lesser of two evils. Another consideration is to have performers learn alternative strategies to thought suppression in order to cope with negative thoughts and feelings. For example, rather than trying to suppress or block thoughts, athletes could explore the source of the thoughts and learn methods of thought or behaviour management such that the unwanted thoughts do not enter consciousness.

Future Directions

The white-bear methodology has routinely been used in thought suppression manipulations (Muraven et al., 1998; Wegner et al., 1987). Despite being commonly thought to induce changes in mental fatigue, there is potential that thought suppression could impact physical performance in other ways as well. Wegner and colleagues (1987) originally theorized that the act of thought suppression could result in the paradoxical emergence of the unwanted thought itself. Along this line of reasoning, researchers have demonstrated that suppressing performance-relevant imagery - such as missing the target when one hits a golf putt, increases the likelihood of eliciting that very behavioural response (Beilock et al., 2001). In the current study, perceptions of effort during the MDT were impacted despite asking participants to suppress the thought of a benign thought target: a white bear, which contained no performance-relevant components. Future studies should look to investigate if trying to suppress task-relevant thoughts, such as images of failure or self-deprecating self-talk have the capacity to impact performance or feelings states in a more profound manner than contrived cognitions such as a white bear.

The present study failed to corroborate the findings of physical performance decrements following bouts of mentally-fatiguing self-control exertion. There is potential however, that the demands of the MDT used in the current methodology were not inherently challenging enough to observe the findings we initially hypothesized. In Marcora and colleagues' (2009) initial study, highly-trained athletes were asked to ride at 80% of their respective maximums, for as long as they possibly could. Although participants in the current study were instructed to perform all-out bouts of cycling; they were also provided the autonomy to select how they paced their behaviour. Interestingly, dRPE values were significantly higher in the mentally-fatiguing condition in the final 3-minutes of the MDT trials, regardless of the dRPE modality being investigated. This trend is of interest when considered together with the HR data from the exercise trials because it appeared to coincide with the point in the task where participants shifted pacing strategies from conservation (i.e., consistent HR), to all-out performance with an abrupt acceleration in HR. Through this portion of the trials, participants perceived leg-muscle, respiration as well as mental exertion were higher. Contrasting the demands of this stage of the MDT, relative to the findings reported during consistently high-demand whole-body endurance exercises (Marcora, et al., 2009), it stands to reason that mental fatigue might not affect objective physical performance until maximal demands are placed on individuals. An interesting avenue for future studies will be to assess the effects of mentally-fatiguing bouts of thought suppression on the subsequent performance of such maximal endurance physical tasks.

Strengths and Limitations

The present study was designed as response to several looming questions in the literature investigating self-control, mental-fatigue and exercise performance. As a result, there are several strengths that should be recognized. One of study's strengths relates to the experimental design. People can have highly varied approaches and responses to exercise (Tucker & Noakes, 2009) which can add substantial error variability when participants contribute data from only one condition in a between-groups study design. In the present study, because all participants completed both experimental protocols in a within-subjects design, random error variance was more effectively controlled. Another noteworthy strength of the study design was that participants were provided a familiarization session prior to completing counterbalanced control and experimental trials. Thus, they were aware of the cycling task demands prior to performing any of the test trials, which helped reduce potential effects associated with differential carry-over effects that can occur when participants lack such knowledge. The use of differential RPE assessments was another methodological strength. By having participants rate perceptions of exertion across multiple sensory modalities, we gained better insight into their specific experiences throughout MDT trials. As recently acknowledged by McLaren et al. (2017), gaining resolution on discrete sensory inputs provides more information than a single gestalt-rating of exertion. As far as we are aware, this is the first study to implement such protocols into a self-control depleting dual-task paradigm.

Training participants to enable them to report dRPE was also a strength in this study. In many studies, participants receive no instructions on how to use the CR-10 RPE rating scale. Participants in this study, were exposed to a full explanation of how to provide valid and reliable RPE scores taken directly from Borg (1998) and gained experience rating dRPE while performing a graded exercise test prior to engaging in any of the experimental tasks.

Despite these strengths, there are also several limitations to make note of. One limitation is that data obtained are from participants who self-described as being physically active and therefore are not generalizable to people who are not active. However, despite all participants meeting the base requirement of 150-minutes/week of activity, there was a relatively large range of self-rated activity levels. Consequently, the findings have the benefit of being generalizable to a population that has varied experience with exercise (i.e., not just those who are highly-trained).

Another potential limitation that was acknowledged initially when designing the study was the fact that participants were provided autonomy regarding exercise intensity during both exercise trials. This decision was based on the fact that when they exercise, people usually have control over the amount of work they do (e.g., how fast they run or pedal). However, it did introduce the possibility that participants might "experiment" with different pacing strategies during the MDTs regardless of the experimental manipulations. The results showed participants paced themselves on both MDTs in a remarkably consistent manner on both trials, which suggests they may have consistently monitored information from the timer to help gauge their speed or selected workloads that were not particularly challenging. Future studies should also investigate the effects of thought suppression on performance and dRPE using exercise tasks that are performed at near-maximal workloads to better simulate the demands of competitive performance.

Conclusion

The present study found that engaging in a 6-minute session of thought suppression increases ratings of perceived exertion during subsequent bouts of whole-body cardiovascular exercise. The thought suppression task also led to increased ratings of mental fatigue. Although negative effects of mental fatigue on physical performance or RPE during exercise have been observed previously, this is the first study to show that an activity (i.e., thought suppression) that athletes might often engage in prior to competing can have undesirable carry-over effects on perceived exertion. Overall, the findings support previous literature indicating that self-control exertion causes increased feelings of mental fatigue, which in turn has the capacity to decrease physical performance or increase ratings of perceived exertion.

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