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

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Abstract

Interventions to attenuate the negative effects of prior self-control exertion on physical performance are limited. The current study had three primary objectives: a) to investigate whether prior self-control exertion reduces subsequent performance on a time-to-exhaustion (TTE) cycling task, b) to investigate if goal priming attenuated the detrimental effects of self-control depletion on subsequent physical performance, c) to examine the potential for any observed performance decrements to be explained by changes in perceptions of pain and motivation. Fourteen recreationally active males (23 ± 3 years) completed three TTE cycling tasks at 80% $\dot{V}O2$ peak on an electromagnetically braked cycle ergometer. Prior to each TTE cycling task, participants completed a self-control depletion condition (incongruent Stroop task) or a non-self-control depletion condition (congruent Stroop task) for 4 min. During the TTE cycling task, participants were asked to watch a video on the screen in front of them. During this video, participants were exposed to a goal priming sequence (intervention condition) or a random letter sequence (control condition). The participants' TTE cycling task performance time, subjective measures, and cycling cadence were recorded every 3 min during the TTE task. A one-way repeated-measures ANOVA revealed that there was no significant difference in TTE cycling task performance between the experimental conditions ($p = 0.28$). Furthermore, there were no significant changes in perceptions of pain ($p = 0.36$) or motivation ($p = 0.21$). The findings indicate that prior self-control exertion did not negatively affect subsequent TTE cycling task performance. In addition, goal priming does not influence the effects of initial self-control exertion on subsequent physical task performance.

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

Introduction

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

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

0.506; Giboin & Wolff, 2019; $g = 0.55$; Hunte et al., 2021) of prior self-control exertion on subsequent physical task performance.

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

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

A movement towards a mechanistic explanation of self-control failures has recently led to an investigation into the variables that may underpin the effects of self-control exertion on subsequent physical performance (Hunte et al., 2021). Recent research has highlighted individuals' perceptions of pain and motivation as two plausible mechanisms. For example, following an initial exertion of self-control, participants reported higher perceptions of pain and reduced motivation during the early stages of a wall-sit task. Participants also quit the wall-sit task sooner when they did initially exert self-control (Boat et al., 2018; Boat & Taylor, 2017). Aligned with the assumptions of the *shifting priorities model* (Inzlicht et al., 2014), it can be suggested that once self-control has become depleted, individuals' attentional foci shift to become focused on feelings of physiological discomfort (i.e., pain), causing shifts in motivational foci towards proximal goals (e.g., quitting or reducing effort to alleviate discomfort and pain), and away from the distal goal (e.g., persisting on the task to achieve optimal performance). Specific to motivation, it has been suggested that more nuanced aspects of motivation, such as task importance, may be a suitable underpinning mechanism that may explain self-control failures (Brown & Bray, 2019; Hunte et al., 2021). In addition, individuals' ratings of perceived exertion (RPE) have been investigated as a potential underpinning mechanism (e.g., Wagstaff, 2014). However, the evidence base regarding the effects of self-control exertion on RPE are limited and often inconsistent (Hunte et al., 2021). Therefore, further examination of perceptions of pain, motivation, and RPE are necessary to strengthen the evidence base regarding these mechanisms, and to develop a better understanding of how self-control exertion affects subsequent endurance performance.

Considering the negative effects of self-control exertion on subsequent physical performance, there is a demand for intervention strategies to reduce these effects (Hunte et al., 2021). One proposed intervention is goal priming (Papies, 2016; Walsh, 2014), which involves providing external cues to individuals, which consequently cause changes in cognition and behavior, often without conscious intention or awareness (Papies, 2016). Goal priming has previously been shown to attenuate the effects of prior self-control exertion on subsequent task performance in a non-exercise setting (i.e., saving money; Walsh, 2014). In addition, goal priming has been found to improve self-control behavior in the face of temptations to over-eat (Papies & Petra, 2010). The application of priming a goal state that is desirable to attain (e.g., optimal performance on a physical task) via the use of goal-related words or cues in the environment, may initiate an increased capacity for participants to exert further self-control (e.g., persevering during a demanding physical task) in pursuit of that goal (see Aarts et al., 2007 for overview). Furthermore, in relation to the aforementioned mechanisms, providing a goal prime related to self-control has the potential to shift attentional and motivational foci away from proximal temptations that induce self-control conflict, and instead towards the distal goal (Aarts, et al., 2007; Inzlicht et al., 2014; Walsh, 2014).

However, the potential for goal priming to attenuate the effects of self-control depletion during a physical task, and the mechanisms underpinning these effects, remain unexplored. Goal priming has been used during a physical task to produce higher levels of effort and performance during endurance-based tasks (e.g., Blanchfield et al., 2014; Takarada & Nozaki, 2018). However, participants were not subject to any cognitive exertion manipulations prior to performance. Given the tenets of the shifting priorities model (Inzlicht et al., 2014) and previous goal priming research (Aarts et al., 2007; Papies & Petra, 2010; Walsh, 2014), it seems reasonable to suggest that following the exertion of self-control, a self-control goal priming intervention could offset the shifts in attentional and motivational foci away from proximal temptations (e.g., feelings of discomfort and quitting the task) and encourage attainment of the distal goal (e.g., optimal performance) during a subsequent physical performance task.

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

Methods

Participants

Fourteen recreationally active males (age 23 ± 3 years, height 183 ± 8 cm, mass 81 ± 10 kg, $\dot{V}O_2$ peak 41.8 ± 7.9 ml.kg^{-1}.min^{-1}) participated in the current study. All participants were healthy, as determined by a university approved general health questionnaire. Participants moderate to vigorous physical activities (MVPA) exceeded public health MVPA guidelines of 150 min per week, whereby, participants reported exercising on average 4 days (*SD* = 2 days) per week for an average duration of 70.20 min (SD = 17.85 min per session). A power calculation (G*Power version 3.1; Faul, Erdfelder, Lang & Buchner, 2007) with power = 0.95 and $\alpha = 0.05$, specified a minimum sample size of *N* = 14 would be satisfactory to detect a medium effect size (0.40), which is representative of previous studies that have examined the effects of self-control exertion on subsequent performance (Brown et al., 2020; Hunte et al., 2021).

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

Procedures

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

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

Following a standardized 30 min rest period, participants were familiarized with all components of the experimental trials (see experimental protocol section). Participants completed all questionnaires (see measures section) and the time to exhaustion (TTE) cycling task to be used during visits 2-4. Participants were also shown a control version of the scanning visual vigilance task (see scanning visual vigilance task section) while they completed the TTE cycling task.

Experimental protocol. The experimental protocol can be found in the *Electronic Supplementary Material: Fig. S1*. Participants were instructed to keep a record of their food intake and activity patterns prior to the first TTE cycling task and to replicate the same diet and exercise activities 24 h before all subsequent trials. Each participant took part in three experimental sessions: non-self-control exertion (congruent Stroop task) with no goal prime intervention (control condition), self-control exertion (incongruent Stroop task) with no goal prime intervention, and self-control exertion (incongruent Stroop task) with goal prime intervention. On arrival at the laboratory, participants completed questionnaires to assess daily stress and fatigue (see measures section). Previous research has recognized the potential for stressful events and feelings of fatigue to reduce an individual’s self-control strength, therefore it was important to control for both variables in the current study (Englert & Rummel, 2016; Graham et al., 2017; Tangney et al., 2004).

The cycle ergometer was then adjusted to the pre-recorded ergonomic measurements. Participants began a standardized warm-up consisting of 3 min at a power output reflective of 40% $\dot{V}O_2$ peak, followed by 2 min at 60% $\dot{V}O_2$ peak. Immediately following the warm-up, participants were required to complete either a self-control depletion or non-self-control depletion experimental manipulation for 4 min. A modified Stroop task (Stroop, 1935) was utilized as the method of depleting individuals’ self-control. This task has frequently been used in similar self-control exertion studies (e.g., Boat et al., 2020; Englert & Wolff, 2015; McEwan et al., 2013). Furthermore, this duration (4 min) of the Stroop task was utilized as previous research has found negative effects on subsequent physical performance following a 4 min Stroop task (e.g., Boat & Taylor, 2017; Boat et al., 2020; Hunte et al., 2022). The Stroop task was completed on a laptop computer, with a head-to-monitor distance of 80–100 cm, via custom-made software (SuperLab 6.0) with words serially presented on the screen. Participants were instructed to respond as accurately and quickly as possible. Stimuli remained on the screen until participants responded. There was an inter-stimulus interval of 1

s. Prior to the actual test, participants completed a practice session lasting 30 s to familiarize themselves with the task and response pad.

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

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

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

Measures

Daily stress. The Daily Inventory of Stressful Events Questionnaire (Almedia et al., 2002) consists of seven statements that asks participants to report whether any number of stressful events had occurred today by circling either "yes" or "no" (e.g., "Anything at home that most people would consider stressful"). This questionnaire has frequently been used to measure daily stress (e.g., Boat et al., 2020) and has been shown to have acceptable internal consistency and predictive validity (Almeida et al., 2002; α = .71 across all conditions).

Perceptions of physical fatigue. Physical fatigue was assessed using two items from the fatigue subscale of the Profile of Mood States (i.e., "I feel physically exhausted and "I feel physically worn out"; McNair et al., 1992). Participants were required to rate their agreement with each item on a five-point scale (1 = not at all true; 5 = very true). These items have shown acceptable factor loadings and reliability in previous research (Beedie et al., 2000; Boat & Taylor, 2017; α = .78 across all conditions).

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

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

Ratings of perceived exertion (RPE). Participant's RPE was also measured verbally using a modified 20-point Borg scale. Whereby participants responded to the statement "please rate your current RPE experienced during this trial" (1 = no exertion at all; 20 = extremely hard) (Borg, 1998). The current scale was modified to align with the scales used to measure pain, motivation and task importance. This scale was adapted for the current study in accordance with previous research (e.g., Taylor et al., 2020) and to provide participants with consistency as they responded to each perceptual measure consecutively.

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

Goal priming procedure. Participants were exposed to supraliminal goal primes during the scanning visual vigilance task (see Electronic Supplementary Material: Fig. S2). Supraliminal primes were selected as they have been shown to have greater and longer-lasting effects on behavior, compared to subliminal primes (Francken et al., 2011). One prime was presented sequentially every 10 s. Each prime sequence consisted of a white fixation cross that was displayed on a dark grey background in the center of the projector screen for 5000 ms. This was instantly followed by a 1000 ms presentation of a random letter string (e.g., TXPSTW) that acted as a forward mask. This was followed by a 1500 ms presentation of our goal prime intervention, or a random letter string (no goal prime intervention). Specifically, the goal prime intervention condition consisted of five expressions related to positively utilizing self-control (determination, exert, continue, maximal effort, persist and sustain). This was followed by another 1000 ms presentation of a random letter string that acted as a backward mask. Finally, a neutral stimulus word (e.g., Garage), with or without a black circle above or below, was displayed for 1500 ms. Based on previous recommendations (Silvestrini & Gendolla, 2011), it was suggested that one third of the prime sequence should consist of a goal prime. Thus, it was ensured that out of every six prime sequences, two consisted of self-control phrases and the remaining four consisted of random letter strings. This was to avoid habituation to the self-control phrases (Blanchfield et al., 2014; Silvestrini & Gendolla, 2011). In the no goal prime intervention condition, no self-control phrases were presented, instead, only random letter strings were presented until the neutral stimulus word, with or without a black circle above or below it, was presented (see Electronic Supplementary Material: Fig. S2). The priming sequence was generated in PsychoPy software (Peirce et al., 2019) and the primes were presented on a 13' laptop screen with an aspect ratio of 16:10, a refresh rate of 60 Hz, and a 1440 x 900-pixel display. From this laptop, the primes were projected onto a 175" screen via a HDMI cable. Similar priming protocols have been used in previous research also employing a physical endurance task (Blanchfield et al., 2014; Takarada & Nozaki, 2018).

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

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

Statistical Analysis

Data were analyzed using SPSS (version 24; SPSS Inc., Chicago, IL, United States). To check for baseline differences between the trials, stress, fatigue, mental exertion, and Stroop task performance were analyzed using one-way repeated measures analysis of variance (ANOVA), with Bonferroni-corrected paired samples t-tests used as post hoc testing where significant differences existed. TTE cycling task performance, mechanisms (perceptions of pain, motivation, task importance, and RPE), and cadence were also analyzed using one-way repeated measures ANOVA (with Bonferroni-corrected paired samples t-tests as post hoc testing, with effect sizes calculated as Cohen's *d*). Previous research has suggested that self-control exertion may negatively impact both initial and overall perceptions (Hunte et al., 2021). Therefore, separate ANOVA analyses were conducted for both initial (i.e., after 3 min) and overall (i.e., average of scores) measurements for potential mechanisms. All data are reported as mean ± standard deviation and 95% CI. Statistical significance was accepted as $p < 0.05$.

Transparency and Openness Statement

We describe our sampling plan, all data exclusions (if any), all manipulations, and all measures in the study, and we adhered to the journal's methodological checklist. All data, analysis code, and research materials are available upon request from the corresponding author Raymon Hunte (Email: r.hunte@londonmet.ac.uk). This study's design and its analysis were not preregistered.

Results

Preliminary Manipulation Checks

Table 1 displays descriptive statistics for each variable across each experimental condition. There was no difference at baseline between the trials for stress (*F*(2,26) = 1.44, *p* = 0.26, *d* = 0.10), or fatigue (*F*(2,26) = 1.13, *p* = 0.86, *d* = 0.01), therefore, it was not necessary to control for these variables. There was a significant difference in participants level of mental exertion between each condition (*F*(2,26) = 23.22, *p* = 0.001, *d* = 0.64). Upon further inspection, mental exertion was significantly lower on the non-self-control with no goal prime intervention condition (2.71 ± 1.38, 95% CI: 1.91 – 3.51) compared to all other trials (self-control exertion with goal prime intervention condition: 5.53 ± 1.87, 95% CI: 4.35– 6.51, *t*(13) = -5.24, *p* = 0.001, *d* = 1.65; self-control exertion with no goal prime intervention condition: 5.93 ± 1.77, 95% 4.90 – 3.51, *t*(13) = -6.11, *p* = 0.001, *d* = 2.02). In addition, this was supported with differences in Stroop task performance. There were significant differences in participants' response time (*F*(2,26) = 4.38, *p* = 0.02, *d* = 0.35). Upon further inspection, participants responded quicker in the non-self-control with no goal prime intervention (1593 ± 270 ms, 95% CI: 1430 – 1757) compared to all other trials (self-control exertion with goal prime intervention condition: 1822 ± 312 ms, 95% CI: 1634 – 2012, *t*(13) = -2.36, *p* = 0.04, *d* = 0.77; self-control exertion with no goal prime intervention condition: 1829 ± 305 ms, 95% CI: 1644 – 2013, *t*(13) = -2.34, *p* = 0.04, *d* = 0.82). Furthermore, there was significant differences in participants' response accuracy between each condition (*F*(2,26) = 4.52, *p* = 0.03, *d* = 0.26). Upon further inspection, participants responded with more accuracy in the non-self-control exertion with no goal prime intervention condition (99.2 ± 0.9%, 95% CI: 98.7 – 99.7) compared to the self-control exertion with no goal prime intervention condition (98.1±1.7%, 95% CI: 97.1 – 99.1, *t*(13) = 2.57, *p* = 0.02, *d* = 0.80). However, there was no significant difference between the non-self-control exertion with no goal prime intervention condition and self-control with goal prime intervention condition (98.7±1.3%, 95% CI: 98 – 99.5, $t(13) = 1.39$, $p = 0.19$, $d = 0.45$). Finally, the study feedback questionnaire found that the goal prime intervention was successfully detected with 100% of participants answering “yes” to seeing performance related words in the goal prime intervention condition. In addition, all participants answered “no” in the no goal prime intervention conditions.

Table 1
Descriptive statistics for mental exertion, daily stress and fatigue (data are mean ± SD).

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

** main effect of trial $p < 0.001$

Table 2
TTE cycling task performance time, pain, motivation, task importance, RPE and cadence across all trials (data are mean ± SD).

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

Cadence (revs·min^{-1})	85.45 ± 5.41	81.46 ± 5.25	81.98 ± 4.91**

** main effect of trial $p < 0.01$

TTE Cycling Task Performance

There was no statistically significant difference in overall TTE cycling task performance between the three experimental conditions ($F(2,26) = 1.35$, $p = 0.28$, $d = 0.09$; Table 2).

Perceptions of Pain, Motivation, and Task Importance

There was no statistically significant difference in participants overall perceptions of pain ($F(2,26) = 1.06$, $p = 0.36$, $d = 0.08$), overall motivation ($F(2,26) = 1.68$, $p = 0.21$, $d = 0.11$), or overall task importance ($F(2,26) = 0.34$, $p = 0.67$, $d = 0.03$) between the experimental trials (Table 2).

Furthermore, there was no statistically significant difference in participant’s initial perceptions of pain ($F(2,26) = 2.25$, $p = 0.13$, $d = 0.15$), initial motivation ($F(2,26) = 0.54$, $p = 0.59$, $d = 0.04$) or initial task importance ($F(2,26) = 0.08$, $p = 0.98$, $d = 0.01$) between the experimental trials (Table 2).

RPE

There was no statistically significant difference in participants overall RPE during the TTE cycling task between the experimental trials ($F(2,26) = 1.01$, $p = 0.38$, $d = 0.07$). In addition, there was no statistically significant difference in participants initial RPE ($F(2,26) = 1.39$, $p = 0.27$, $d = 0.11$) between the experimental trials (Table 2).

Cadence

Overall, participant’s average cycling cadence was significantly different between the trials ($F(2,26) = 9.19$, $p = 0.001$, $d = 0.41$). Upon further inspection, cycling cadence was significantly higher during the self-control exertion with goal prime intervention condition (85 ± 1 rev.min^{-1}, 95% CI: 82 – 89 rev.min^{-1}) compared to all other trials (self-control exertion with no goal prime intervention condition: 81 ± 1 rev.min^{-1}, 95% CI 78 – 84 rev.min^{-}

^{1}, $t(13) = 4.21$, $p = 0.001$, $d = 0.73$; non-self-control exertion with no goal prime intervention condition: 81 ± 1 rev.min^{-1}, 95% CI 79 – 85 rev.min^{-1}, $t(13) = 3.66$, $p = 0.003$, $d = 0.68$). However, there was no difference in average cycling cadence between the self-control exertion with no goal prime intervention condition and the non-self-control exertion with no goal prime intervention condition ($t(13) = 0.47$, $p = 0.65$, $d = 0.08$) (Table 2).

Discussion

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

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

Another key finding of the present study was that perceptions of pain, motivation, task importance, and RPE were unaffected by prior self-control exertion. This finding is contrary to previous research which suggests that self-control exertion results in higher perceptions of pain and RPE, and lower motivation and task importance (Boat et al., 2018; Boat et al., 2020; Boat & Taylor, 2017; Brown & Bray, 2019; Hunte et al., 2021; Wagstaff, 2014). One plausible explanation may be the difference in time-points at which the mechanistic measurements were obtained. In previous research, differences in initial mechanistic measures have been found when measurements were obtained at 30 s (e.g., Boat et al., 2018; Boat et al., 2020; Boat & Taylor, 2017), whereas, in the present study measurements of mechanisms were recorded at 3 min. From a shifting priorities model perspective (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2017), it could be suggested that after 3 min, initial shifts in attentional and motivational foci had elapsed, resulting in initial perceptions of pain, motivation, task importance, and RPE plateauing. Future research should determine exactly when attentional and motivational priorities shift towards proximal temptations (Boat et al., 2018; Milyavskaya & Inzlicht, 2017). This will provide further understanding into the mechanisms that underpin the effects of self-control exertion on subsequent physical performance, which is pivotal to inform the design of future interventions aimed at attenuating the effects of prior self-control exertion. Alternatively, researchers could explore employing other interventions to attenuate the effects of prior self-control exertion on subsequent physical performance. For instance, this could include self-control training (Friese et al., 2017), providing motivational incentives (Brown & Bray, 2017) or biofeedback (Brown & Bray, 2019). Specifically, when participants were provided with heart rate biofeedback, following the depletion of self-control, participants performed at a similar exercise-intensity and work-rate during a cycling task to the non-self-control group (Brown & Bray, 2019). Findings highlight that biofeedback attenuates the negative effects of prior cognitive exertion, as such, further research is necessary to understand how biofeedback may interact with self-control processes in different physical performance tasks.

Based on previous research in non-exercise settings (Blanchfield et al., 2014, Takarada & Nozaki, 2018; Walsh, 2014), it was hypothesized that goal priming would attenuate the effects of prior self-control exertion on subsequent physical task performance. The present study did not find support for this hypothesis. Although all participants reported detecting the goal prime (as assessed by the study feedback questionnaire) and steps were taken to reduce cognitive demand during the scanning visual vigilance task, it is possible that instructing participants to maintain focus on a video whilst cycling placed equivalent demand on self-control processes throughout each experimental condition. Future research could attempt to provide the goal prime before, or in preparation, for the performance task. This approach may reduce the cognitive demand during the physical task and ensure that the goal prime intervention is still delivered close to the “critical situation” where behavior change must take place (i.e., exerting additional self-control to override the discomfort and strive for optimal performance) (Papies, 2016). Furthermore, goal priming should not be completely disregarded as a potential intervention technique, as it could be suggested that due to the current results finding no effect of prior self-control exertion on physical performance there was no effect for the intervention to mitigate to begin with. Therefore, the potential for goal priming to attenuate the effects of self-control may have been present if the effect was witnessed. Future research could explore the use of goal priming during isometric physical tasks which have been found to be more susceptible to the effects of prior self-control exertion (Hunte et al., 2020). Such investigation would be valuable in exploring the possibility of using goal priming as an intervention to attenuate the negative effects of self-control exertion.

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

Limitations and future research directions `

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

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

In addition, the exclusion of female participants in the current study must be noted as a limitation. The absence of female representation in the study participants may limit the generalizability and external validity of the findings. Consequently, any applicability of findings to the broader population, including female athletes, may be compromised, and caution should be exercised when inferring the results beyond the male cohort studied. Future research should aim to address this limitation by including both male and female participants in investigations into interventions for self-control exertion.

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

Conclusion

The findings of the present study provides evidence that initial self-control exertion and a goal prime intervention do not affect performance on a subsequent TTE cycling task. Furthermore, self-control exertion and a goal prime intervention did not lead to shifts in attentional and motivational foci during a subsequent physical endurance task. However, goal priming did increase participants cycling cadence, with participants cycling at a higher cadence in the self-control exertion and goal priming intervention Finally, debates regarding the exertion of self-control must consider that any observed effects may be dependent on the timing of performance and mechanism inspection; an area which warrants further research.

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