Self-control exertion and caffeine mouth rinsing: effects on cycling time-trial performance

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Abstract

Objectives

The exertion of self-control has been associated with impaired performance on subsequent physical tasks also requiring self-control. However, the effect in well-trained individuals, and of nutritional intervention strategies to reduce the impact of self-control exertion are unknown. This study, therefore, explored the effect of self-control exertion on endurance performance, and pacing strategies, in well-trained individuals. A further aim was to examine the potential for a caffeine mouth rinse to attenuate any decrements in performance due to self-control exertion.

Method

Following familiarization, fifteen trained male cyclists completed four simulated 10 km cycling time-trials on a cycle ergometer. Prior to each time-trial, participants completed a congruent Stroop task, or an incongruent Stroop task, to manipulate self-control. They also received either a caffeine (containing 40 mg of dissolved caffeine) or placebo mouth-rinse prior to, and every 2 km during, the cycling time-trial. The participants' performance time, subjective measures (perceived pain, motivation, task importance, and RPE), heart rate, and blood lactate concentration were recorded throughout the time-trials. Data were analysed using three-way (self-control*caffeine*split time) repeated measures ANOVA.

Results

There was no effect of self-control or caffeine on overall 10 km performance time (all $p > 0.05$). However, following self-control exertion, split time was significantly slower at 3 km ($p = 0.031$) and 5 km ($p = 0.034$), and tended to be slower at 1 km ($p = 0.088$) and 7 km ($p = 0.078$). There was no effect of the caffeine mouth rinse, nor did this interact with self-control, to affect split times (all $p > 0.05$). Prior self-control exertion and a caffeine mouth rinse did not influence perceptions of pain, motivation, and task importance in well-trained individuals (all $p > 0.05$).

Conclusions

Findings suggest that prior self-control exertion affects self-regulatory pacing strategies during the first 7 km of a 10 km cycling time-trial, in well-trained individuals. However, caffeine mouth rinsing does not attenuate the effects of self-control exertion on subsequent endurance performance.

Keywords: ego depletion, pain, motivation, task importance, pacing

Introduction

Self-control refers to any effort by an individual to alter his or her inner states or responses; this includes actions, thoughts, feelings, as well as task performances (Baumeister, Vohs, & Tice, 2007). Self-control is a key aspect of inhibitory control; an important component of the cognitive domain of executive function (Boat & Cooper, 2019; Diamond, 2013). Self-control is vital for optimal athletic performance, whereby it is essential for athletes to regulate their cognitive, emotional, and motor processes (Englert, 2016). For instance, athletes who engage in prolonged physiological efforts at high intensity are required to resist discomfort and the temptation to reduce effort, and instead to invest sustained effort to produce optimal performance (Taylor, Boat, & Murphy, 2018). Self-control capacity can differ between individuals (i.e., trait self-control), as well as within individuals across situations (i.e., state self-control; Tangney, Baumeister, & Boone, 2004). Concerning state self-control, meta-analytic evidence has indicated that following the exertion of self-control on one task, individuals usually have a reduced ability to self-regulate when performing a second, ostensibly unrelated, task (Brown et al., 2020; Giboin & Wolff, 2019). This is commonly referred to as the depletion effect.

This depletion effect has also been examined concerning exercise performance, with a large body of evidence suggesting that prior exertion of state self-control can lead to impaired performance on subsequent physical tasks also requiring self-control. To explore this effect, many studies have asked participants to hold an isometric handgrip squeeze for as long as possible as their physical performance measure (e.g., Bray, Graham, Martin Ginis, & Hicks, 2011; Bray, Martin Ginis, Hicks, & Woodgate, 2008; Muraven, Tice, & Baumeister, 1998; Muraven & Shmueli, 2006; Tice, Baumeister, Shmueli, & Muraven, 2007). For instance, following the completion of a task requiring self-control (incongruent Stroop task), participants were unable to sustain an isometric handgrip squeeze for as long, compared to when they completed a task requiring no self-control (congruent Stroop task) (Bray et al., 2011; Bray et al., 2008). Although squeezing a handgrip primarily requires muscular endurance, overcoming fatigue or pain and overriding the urge to quit are acts that require self-control (Muraven et al., 1998).

Recently, researchers have strived to employ physical tasks that involve more complex human performance, in an attempt to enhance the ecological validity of the evidence, regarding self-control exertion and exercise performance. For instance, following the completion of a task requiring self-control (incongruent Stroop task), trained cyclists performed significantly worse on a simulated 16 km cycling time-trial, compared to when they completed a task requiring no self-control (congruent Stroop task) (Boat, Taylor, & Hulston, 2017). The ability for self-control exertion to reduce subsequent physical performance has been corroborated in press-up, wall-sit, and cycling tasks (e.g., Boat & Taylor, 2017; Dorris, Power, & Kenefick, 2012; Englert & Wolff, 2015; Wagstaff, 2014).

In addition, mental fatigue has been found to impair subsequent endurance performance. For instance, following a 90 minute demanding cognitive task (the AX-Continuous Performance Task; Carter, Braver, Barch, Botvinick, Noll, & Cohen, 1998), aerobically trained participants reached their maximal level of perceived exertion and disengaged earlier during a subsequent cycling trial at 80% peak power output, compared to when they completed a control task (90 minutes of watching emotionally neutral documentaries; Marcora, Staiano, & Manning, 2009). The impairment of exercise performance following mental fatigue has been replicated in running and cycling tasks (e.g., MacMahon, Schücker, Hagemann, & Strauss, 2014; Martin et al., 2016). Although there appears to be a significant difference between self-control exertion and mental fatigue (Englert, 2016); for instance, tasks that are utilized to induce mental fatigue usually last considerably longer (~90 min) than the tasks that are employed in self-control depletion research (~4-10 min); both self-control depletion and mental fatigue appear to reduce subsequent performance on physical tasks that require prolonged effort (Brown et al., 2020). Specifically, with regards to self-control exertion, research has begun to examine the mechanisms underpinning performance decrements on subsequent physical tasks (e.g., Boat, Atkins, Davenport, & Cooper, 2018).

The major theoretical model that has been utilized to explain self-control failures following a primary self-control act is the *strength model of self-control*, which implies that performance on tasks requiring self-control draws energy from an internal resource (Baumeister, Bratslavsky, Muraven & Tice, 1998; Muraven et al., 1998). This resource is limited and is consumed by use; consequently, it is vulnerable to becoming depleted over time (Baumeister et al., 1998). The state of self-control resource depletion is termed '*ego depletion'* (Baumeister et al., 1998). Following self-control use, an individual's capability to exert further self-control becomes diminished, resulting in reduced performance on subsequent acts of self-control (Hagger et al., 2010). However, this resource explanation has come under severe criticism (e.g., Kurzban, 2010; Lange & Eggert, 2014), with recent replication studies and commentaries raising doubts regarding the validity of the strength model (e.g., Carter, Kofler, Forster, & McCullough, 2015; Wolff, Baumann, & Englert, 2018; Wolff, Sieber, Bieleke, & Englert, 2019). For instance, studies have established methods to sustain self-control, such as incentives (e.g., Muraven & Slessareva, 2003), meditating (Friese, Messner & Schaffner, 2012), and providing choice (Moller, Deci & Ryan, 2006). The identification of the resource that is depleted also remains elusive (Taylor et al., 2018).

An alternative perspective is the *shifting priorities model of self-control* (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2018), a model based upon motivational and attentional processes. This shifting priorities model proposes that self-control diminishes due to a subjective valuation process, in which distal and proximal goal choices are repeatedly appraised (Berkman, Livingston, Kahn, & Inzlicht, 2015). Following self-control exertion, attentional and motivational foci shift, whereby the value of exerting further self-control in pursuit of the distal goal reduces, while the value of conceding to the tempting proximal goal is increased (De Witt Huberts, Evers, & de Ridder, 2014; Kool & Botvinick, 2014). Ultimately, self-control indicates a choice to apply effort to resist a tempting proximal goal in favour of a distal goal (Milyavskaya & Inzlicht, 2018).

Recent research has used individual's perceptions of pain and motivation during physically effortful tasks, in line with the shifting priorities perspective. For instance, following prior self-control exertion, recreationally active participants reported higher perceptions of pain and motivation during the early stages of a lower limb endurance task (wall-sit task), which led to a reduction in persistence during the task; relative to when participants did not initially exert self-control (Boat & Taylor, 2017; Boat et al., 2018). It appears that during physically effortful tasks, prior self-control exertion leads to an attentional shift towards perceptions of physiological sensations (e.g., pain), resulting in motivational priorities shifting towards an increased focus on the proximal goal (e.g., quitting or reducing effort to relieve the pain/discomfort), compared to the distal goal (e.g., persisting on the task to optimize performance), resulting in performance decrements.

This growing body of theoretical and empirical evidence that shifting attentional and motivational focus can explain self-control reductions during simple measures of physical performance. Exploring changes in perceptions of pain and motivation to perform subsequent task goals, throughout endurance performance, would provide a novel insight into the mechanisms underpinning the shifting priorities model and how this affects performance across time (i.e., pacing strategies; Boat et al., 2017; Englert & Wolff, 2015). Similarly, explicit measures of task importance could contribute to this debate, by examining participant's perceptions of proximal goal focus (i.e., reducing exercise intensity to relieve pain) relative to distal goal focus (i.e., maintaining exercise intensity to enhance performance time).

To date, the tenants of the shifting priorities model (Inzlicht & Schmeichel, 2016) have only been examined in recreationally active individuals, and has yet to be explored using sports specific tasks that require self-control (e.g., cycling time-trial) in well-trained individuals. In trained populations, the continued pursuit of the same cognitive goal leads to the automatization of cognitive processes (Williams, Huang, & Bargh, 2009). When this occurs, self-control resources may not be required to the same degree as conscious self-control in novice performers (Schmeichel & Baumesiter, 2004). Consequently, from a shifting priorities perspective (Inzlicht & Schmeichel, 2016), engaging in an initial task requiring self-control may not cause attentional and motivational foci to shift because conscious self-control is not required in expert performers (Baumeister & Bargh, 2014; Englert, 2019). Alternatively, optimal endurance performance will evoke high levels of discomfort and overcoming these demands may heighten the need for conscious self-regulation. As a result, even in expert populations, the initial exertion of self-control may lead to shifts in attention and motivation, because the self-control necessary to persist on the task to optimize performance and resist the discomfort is salient (Boat et al., 2017).

Given the effect of self-control exertion on subsequent physical performance, recent research has started to examine nutritional intervention strategies to counteract these effects (e.g., Boat et al., 2017). One proposed nutritional intervention is caffeine, due to the well-documented effects of caffeine ingestion on perceptions of exertion (Doherty & Smith, 2005), perceptions of pain (Astorino, Cottrell, Talhamj, Aburto-Pratt, & Duhon, 2012), and endurance exercise performance (e.g., Cox et al., 2002). More recently, research has suggested that a caffeine mouth rinse may elicit similar physiological benefits (Kamimori, Karyekar et al., 2002; Bottoms et al., 2014). One of the proposed mechanisms by which caffeine affects exercise performance is the antagonism of adenosine receptors (Ribeiro & Sebastiao, 2010); with such receptors known to be present in the cheek pouch of mammals (Rubinstein, Chandilawa, Dagar, Hong, & Gao, 2001). In brief, it is speculated that when caffeine antagonises adenosine receptors, perceptions of effort and pain may be reduced, and motivation for the exercise task maintained (Bottoms et al., 2014). Given that perceptions of pain and motivation are key tenants of the shifting priorities model explaining the effects of self-control exertion on subsequent physical performance (Inzlicht & Schmeichel, 2016), it seems reasonable to suggest that a caffeine mouth rinse may attenuate the reduction in physical performance following self-control exertion. However, this has not been examined to date, yet this line of enquiry is significant given the recent call for research to explore intervention strategies to attenuate the impact of self-control exertion.

Therefore, the aims of the current research were to determine a) whether exerting self-control reduces endurance performance in well-trained individuals, b) how self-control exertion affects the pacing strategies adopted during endurance performance, c) whether exerting self-control increases perceptions of pain, and reduces perceived motivation and task importance, during a subsequent exercise performance task, and d) the potential for a caffeine mouth rinse to attenuate any decrements in performance due to self-control exertion.

Based on the broad self-control literature (Boat et al., 2017; Boat et al., 2018; Dorris et al., 2012; Englert & Bertrams, 2012; Englert & Wolff, 2015), it was hypothesized that self-control exertion would result in reduced 10 km cycling time-trial performance in well-trained individuals (hypothesis 1), that this performance decrement would be underpinned by changes in pacing strategy, as a result of self-control exertion (hypothesis 2), and that self-control exertion will lead to increased perceptions of pain, and reduced perceptions of motivation and task importance (hypothesis 3). In addition, the study will also examine whether a caffeine mouth rinse attenuates any of these effects. However, this element of the study is exploratory due to the novelty of this intervention strategy with regards to self-control exertion.

Method

Participants

Fifteen endurance recreationally trained male cyclists (age 22.4 ± 2.56 years, height 178.9 ± 5.7 cm, mass 78.7 ± 7.9 kg, body mass index 24.3 ± 1.6 $kg \cdot m^{-2}$) took part in the study. Inclusion criteria required that all participants were currently training for a cycling-based event (e.g., triathlon, road cycling). The participants spent, on average, 8 hours (*SD* = 3 hours) per week training. A power calculation (G*Power version 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) with power = .95 and α = .05, specified a minimum sample size of *N* = 15 would be satisfactory to detect a medium effect size (.40), which is representative of previous studies that have examined the effects of self-control exertion on subsequent physical performance (Brown et al., 2020).

Following approval from a university ethics committee, each participant signed an informed consent form after the study was explained in full and it was clarified that involvement was anonymous and voluntary. All participants were healthy, as assessed by a university approved general health questionnaire, which assessed physical, psychological, and neurological health. Furthermore, participants were instructed to avoid vigorous exercise, and to not consume any alcohol/caffeine, during the 24 hours prior to the experimental trials. Participants were also encouraged to arrive to the laboratory 4 hours postprandial. Adherence to these requirements were verbally confirmed by all participants on arrival to the laboratory.

Procedures

Data collection involved five laboratory sessions in total. Participants were familiarized with the experimental procedure in session 1, whereas sessions 2-5 comprised the experimental trials. This study utilized a double-blind, randomized, cross-over design, and each trial was separated by at least 48 hours. All trials were performed at the same time of day to avoid natural fluctuations in physiological parameters due to variation in circadian rhythm.

Familiarization. At least one week before the first experimental trial, participants completed a familiarization visit. During this session, height and body mass were measured. Participants then completed a simulated 10 km time-trial, as fast as possible, using a cycle ergometer (Watt Bike Pro, Watt Bike) against a fixed resistance at a freely chosen velocity. Participants received no encouragement or information except a signal that they had 2 km and 1 km of the time-trial remaining. Music and external distracting material was eliminated during all experimental trials. During the familiarization, ergonomic aspects such as seat and handlebar position were obtained and replicated for all subsequent trials. A time-trial protocol was employed due to its greater ecological validity, compared to time to exhaustion protocols, as performance and physiological responses are similar to outdoor time-trials (Currel & Jeukendrup, 2008). Furthermore, this task necessitates many behaviors that require self-control such as overcoming physical discomfort, resisting the urge to quit, pacing, and regulating emotion and attention during physical stress (Martin et al., 2016). The distance of 10 km was chosen because it is common in road cycling.

Experimental protocol. The experimental protocol can be found in figure 1. Participants were instructed to keep a record of their food intake and activity patterns on the day before the first experimental trial and to replicate the same diet and exercise activities 24 hours before all subsequent trials. Adherence to physical activity and food intake was verbally confirmed by all participants on arrival to the laboratory. Each participant took part in four experimental sessions (self-control exertion with caffeine mouth-rinse, self-control exertion with placebo mouth-rinse, non-self-control exertion with caffeine mouth-rinse, non-self-control exertion with placebo mouth-rinse). Participants first completed questionnaires to control for the influence of daily stress and physical fatigue (see measures section; Englert & Rummel, 2016; Tangney et al., 2004). Participants were then fitted with a heart rate monitor (Polar RS100, Polar Electro) and completed a standardized warm-up (5 min of cycling).

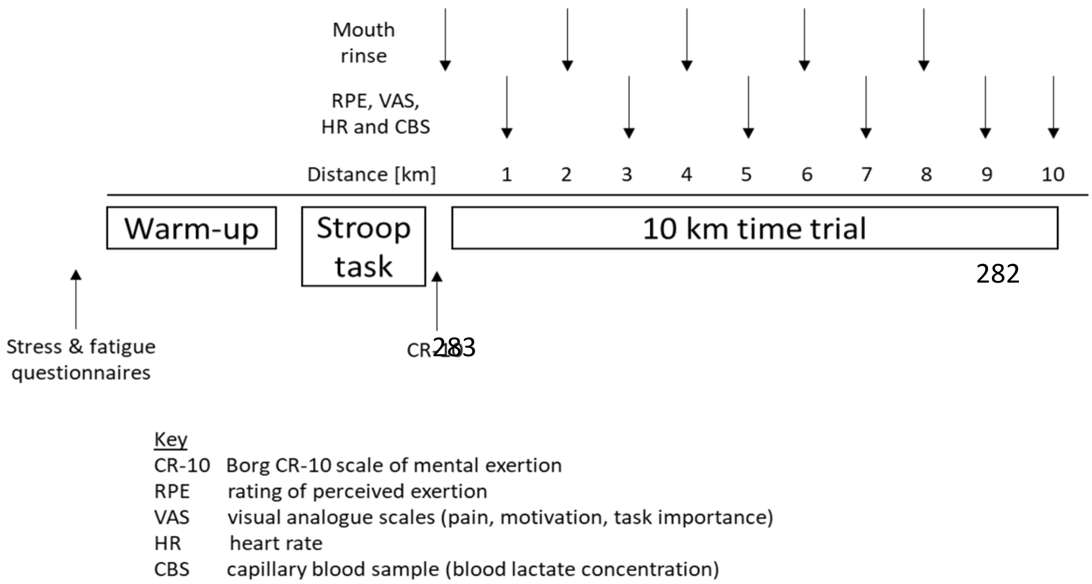

Figure 1: Experimental protocol demonstrating the timing of each measurement during the experimental trials.

Immediately following the warm-up, participants were required to complete either a self-control or non-self-control experimental manipulation. A modified Stroop task (Stroop, 1935) was used as the experimental manipulation in this study. The Stroop tasks were completed on a laptop computer, with a head to monitor distance of 80-100 cm, via custom-made software (Loughborough Cognitive Test Battery). The Stroop task involved the target word being presented in the centre of the screen, with two optional responses to either side; the participant had to select the correct response using the arrow keys on the laptop computer keypad. For each stimulus, the target and responses remained on the laptop computer screen until the participant responded. There was an inter-stimulus interval of 1 s. In the self-control exertion trial, the text and color of the target word were always incongruent (e.g., green, written in blue font) and participants had to select the color of the word, not the word itself. Previous studies have advocated that the incongruent version of the Stroop task is cognitively challenging and requires self-control, because individuals have to volitionally override their primary impulse of selecting the word as opposed to the font color (e.g., Englert & Wolff, 205; McEwan, Martin Ginis, & Bray, 2013). In the non-self-control exertion trial, the text and color of the target word were always congruent (e.g., green, written in green font). Each Stroop task contained 160 trials, lasting approximately 4 minutes. This duration of the incongruent and congruent Stroop tasks were utilized as previous self-control research has successfully employed this task for the same length of time (i.e., 4 minutes) (e.g., Boat et al., 2018).

The Stroop task was completed in a quiet room to minimise distractions. Participants were instructed to respond as accurately, and as quickly as possible. To ensure that participants were familiar with what was required during the Stroop task, each Stroop test was preceded by 6 practice stimuli, where feedback regarding whether responses were correct was provided. Prior to the start of the experimental trial, both the participants and the experimenters were blinded to the self-control manipulation. Immediately following the Stroop task, participants completed a manipulation check using the CR-10 scale (Borg, 1998), which examined their perceived mental effort during the Stroop task (see measures section); before proceeding to start the cycling time-trial.

The caffeine experimental manipulation took place immediately after the Stroop task. Participants were administered either a caffeine mouth rinse (40 mg caffeine dissolved in 25 ml of a water and sugar free, non-caffeinated, lemon and lime squash solution) or a taste, texture, and color matched placebo. Participants rinsed this solution around their mouth for 10 s, and then expectorated the fluid back into a bowl. This volume of caffeine was selected as it is typically found in commercially available caffeinated drinks. The pre- and post-rinsing solution weight was assessed to ensure that none of the solution was ingested. In addition, the dose of caffeine administered, and the mouth rinse protocol and solution, were determined from previous research investigating the effect of caffeine mouth rinsing on endurance cycling time-trial performance (e.g., Bottoms et al., 2014; Doering, Fell, Leveritt, Desbrow, & Shing, 2014). Participants and all researchers who had contact with the participants were unaware of treatment order and were blinded to the identity of the caffeine and placebo solutions.

Immediately after the rinse solution, participants commenced a simulated 10 km cycling time-trial. Participants were administered a further mouth rinse solution at 2 km, 4 km, 6 km, and 8 km during the time-trial. Outcome variables were performance (split-time), perceived pain, motivation, and task importance, heart rate, blood lactate concentration, as well as rating of perceived exertion (RPE) (for details see measures section). These were recorded at 1 km, 3 km, 5 km, 7 km, and 9 km, during the time-trial, and immediately upon completion of the time-trial. All experimental trials were completed under similar environmental conditions (19-21°C dry bulb temperature and 50-60% humidity). Standing floor fans, always in the same position and fan speed, were available to participants to minimize thermal stress.

Measures

Daily stress. Daily stress was measured using the seven stem questions from the Daily Inventory of Stressful Events Questionnaire (Almeida, Wethington, & Kessler, 2002). Participants were instructed to report whether any of a number of stressful events had occurred today by circling either ‘yes’ or ‘no’ (e.g., “Anything at home that most people would consider stressful”). The items have demonstrated acceptable internal consistency and predictive validity in previous research (Almeida et al., 2002).

Perceptions of physical fatigue. Physical fatigue was assessed using two items from the fatigue subscale from the Profile of Mood States (McNair, Lorr, & Droppleman, 1992; i.e., “I feel physically worn out” and “I feel physically exhausted”). Participants were asked to consider the degree to which they were currently experiencing the items on a five-point scale anchored by 1 (*not at all true*) to 5 (*very true*). These items were selected as they demonstrated high factor loadings in previous research and acceptable reliability (e.g., Beedie, Terry, & Lane, 2000), and have been used previously in research of a similar nature (e.g., Boat & Taylor, 2017).

Mental exertion. Following the completion of the Stroop task**,** participants rated their mental exertion using Borg’s single-item CR-10 scale (Borg, 1998; 0 = *extremely weak*; 10 = *absolute maximum*). This single item measure has been shown to be a valid measure in previous research (e.g., McEwan et al., 2013) and has been used previously in research of a similar nature (e.g., Boat et al., 2018).

Perceptions of pain, motivation, and task importance. Participants’ perceptions of pain, perceived motivation to continue with the cycling time-trial, and perceived task importance were measured using Visual Analog Scales (VAS), adapted from the short-form McGill pain questionnaire (SF-MPQ; Melzack, 1987). In brief, the VAS consisted of a 10 cm line and participants were asked to indicate their current perception of pain, motivation, and task importance by making a mark on the line. At either end of the 10 cm line were anchors (pain: ‘no pain’ to ‘worst pain possible’; motivation: ‘zero motivation to continue with the cycling task’ to ‘full motivation to continue with the cycling task’; task importance: ‘full focus on quitting the cycling task to relieve the pain’ to ‘full focus on continuing with the cycling task’). The VAS have previously been used in self-control research to explore participants’ perceptions of pain, motivation, and task importance during physical tasks (e.g., Boat et al., 2018; Boat & Taylor, 2017; Osbourne & Gatt, 2010), and have demonstrated acceptable reliability and predictive (e.g., Wright, Asmunds, & McCreary, 2001).

Ratings of perceived exertion. Participants rated their RPE verbally using the 6 to 20 point Borg scale (6 = *no exertion at all*; 20 = *extremely hard*) (Borg, 1982).

Blood lactate concentration. Capillary blood samples (20 µl) were collected into capillary tubes containing electrolyte balanced heparin (*safe*CLINITUBES, Radiometer, Copenhagen, Denmark,), and analysed immediately (BIOSEN C-line, EKF, London, United Kingdom) for the determination of blood lactate concentration.

Data analysis

All data were analysed using SPSS (version 25; SPSS Inc., Chicago, IL., USA). To check for baseline differences between the trials, stress, fatigue and mental exertion were analysed using one-way repeated measures analysis of variance (ANOVA). Stroop test performance was compared between self-control and non-self-control trials using paired samples *t*-tests. Performance times (overall performance time and split times at 1 km, 3 km, 5 km, 7 km and 9 km) were initially analysed using three-way (self-control: self-control exertion vs. non-self-control exertion; caffeine: caffeine mouth rinse vs. placebo mouth rinse; split time: 1 km vs. 3 km vs. 5 km vs. 7 km vs. 9 km vs. 10 km) repeated measures ANOVA. Subsequently, to examine the effect on pacing strategy, two-way (self-control: self-control exertion vs. non-self-control exertion; caffeine: caffeine mouth rinse vs. placebo mouth rinse) repeated measures ANOVA were conducted at each time-point; with appropriate Bonferroni adjustments (with corrected *p* values reported). Subjective scales (perceived pain, motivation and task importance; at 1 km, 3 km, 5 km, 7 km, 9 km and upon completion of the 10 km time trial) and physiological parameters (heart rate, rating of perceived exertion and blood lactate concentration; at baseline, 1 km, 3 km, 5 km, 7 km, 9 km and upon completion of the 10 km time trial) were also analysed initially using three-way (self-control*caffeine*split time) repeated measures ANOVA, followed by two-way (self-control*caffeine) repeated measures ANOVA at each time-point; with appropriate Bonferroni adjustments (with corrected *p* values reported). Effect sizes for ANOVA are presented as partial eta squared (η_p^2); interpreted as per convention (i.e., small: 0.01; medium: 0.06; large: 0.14). Effect sizes for paired samples t-test are reported as Hedges' *g*; interpreted as per convention (i.e., small: 0.2; medium: 0.5; large: 0.8). Data are presented as mean ± standard error of the mean (SEM) and for all analyses, statistical significance was accepted as $p < 0.05$.

Results

Pre-trial manipulation checks

There was no difference at baseline between the trials for stress ($F_{(3,42)} = 0.9$, $p = 0.427$, $\eta_p^2 = 0.063$) or fatigue ($F_{(3,42)} = 0.7$, $p = 0.535$, $\eta_p^2 = 0.050$). The manipulation of self-control did however affect mental exertion, as measured by the CR-10 scale, with participants reporting greater mental exertion on the self-control exertion trials compared to the non-self-control trials (self-control: 4 ± 1; non-self-control: 2 ± 0; $F_{(3,39)} = 13.7$, $p < 0.001$, $\eta_p^2 = 0.513$). This was confirmed with differences in Stroop test performance between the self-control and non-self-control conditions, whereby, participants responded slower (self-control: 2049 ± 139 ms; non-self-control: 1562 ± 22 ms; $t_{(14)} = -3.5$, $p = 0.004$, $g = 1.234$) and with less accuracy (self-control: 95.8 ± 0.8 %; non-self-control: 98.3 ± 1.6 %; $t_{(14)} = 4.1$, $p = 0.001$, $g = 0.941$) on the self-control, compared to non-self-control, trials. In addition, the pre- and post-rinsing solution weight was not different between trials (all $p > 0.05$) confirming participants did not ingest the mouth rinse solutions.

Performance time

Overall performance time and split performance times (at 1 km, 3 km, 5 km, 7 km and 9 km) are shown in table 1.

Table 1: Performance time across the four trials (data are mean ± SEM)

		Self-control exertion with caffeine mouth rinse	Self-control exertion with placebo mouth rinse	Non-self-control exertion with caffeine mouth rinse	Non-self-control exertion with placebo mouth rinse
Overall 10 km time [s]		990 ± 23	996 ± 23	986 ± 23	989 ± 24
Split times [s]	1 km	100 ± 3	103 ± 5	99 ± 3	100 ± 3 *
	3 km	300 ± 8	304 ± 9	295 ± 7	298 ± 9 **
	5 km	501 ± 12	505 ± 13	494 ± 12	497 ± 14 **
	7 km	701 ± 16	706 ± 18	695 ± 16	697 ± 18 *
	9 km	899 ± 21	904 ± 21	893 ± 21	896 ± 22

* Main effect of self-control, p < 0.05; ** main effect of self-control, p < 0.10.

Overall 10 km performance time. The overall 10 km performance time was not affected by the manipulation of self-control (main effect of self-control, $F_{(1,14)} = 1.8$, $p = 0.202$, $\eta_p^2 = 0.113$) or the caffeine mouth rinse (main effect of caffeine, $F_{(1,14)} = 0.5$, $p = 0.489$, $\eta_p^2 = 0.035$), nor did they interact (self-control*caffeine interaction, $F_{(1,14)} = 0.1$, $p = 0.816$, $\eta_p^2 = 0.004$).

Split times. When considering the split times, there was no three-way (self-control*caffeine*split time) interaction for performance time ($F_{(5,70)} = 0.1$, $p = 0.885$, $\eta_p^2 = 0.002$). However, there was a tendency for performance time to be slower on the self-control exertion trials, compared to the non-self-control exertion trials (self-control: 584 ± 14 s; non-self-control: 578 ± 14 s; main effect of self-control: $F_{(1,14)} = 3.9$, $p = 0.067$, $\eta_p^2 = 0.219$), an effect which was different across time (self-control*split time interaction: $F_{(5,70)} = 1.1$, $p = 0.037$, $\eta_p^2 = 0.268$). However, there was no effect of the caffeine mouth rinse on performance time ($F_{(1,14)} = 0.5$, $p = 0.484$, $\eta_p^2 = 0.036$), nor was this effect different across time (caffeine*split time interaction: $F_{(5,70)} = 0.1$, $p = 0.985$, $\eta_p^2 = 0.009$).

Upon further consideration of the split times, there was a tendency for performance time to be slower on the self-control exertion trials at 1 km, when compared to the non-self-control trials (self-control: 101 ± 4 s, non-self-control: 99 ± 3 s; main effect of self-control, $F_{(1,14)}$ = 3.4, p = 0.088, η_p^2 = 0.193; figure 2a). Performance time was also significantly slower on the self-control exertion trials at both 3 km (self-control: 302 ± 9 s, non-self-control: 297 ± 8 s; main effect of self-control, $F_{(1,14)}$ = 5.8, p = 0.031, η_p^2 = 0.291; figure 2b) and 5 km (self-control: 503 ± 13 s, non-self-control: 495 ± 17 s; main effect of self-control, $F_{(1,14)}$ = 5.5, p = 0.034, η_p^2 = 0.283; figure 2c), compared to the non-self-control depletion trials. There was also a tendency for performance time to be slower on the self-control exertion trials at 7 km (self-control: 703 ± 17 s, non-self-control: 696 ± 21 s; main effect of self-control, $F_{(1,14)}$ = 3.6, p = 0.078, η_p^2 = 0.206; figure 2d), compared to the non-self-control trials. However, there was no effect of self-control exertion on the 9 km split time (main effect of self-control, $F_{(1,14)}$ = 2.5, p = 0.133, η_p^2 = 0.154). There was no effect of the caffeine mouth rinse (main effects of caffeine, p = 0.272-0.551, η_p^2 = 0.024-0.084), nor did the caffeine mouth rinse alter the effect of self-control exertion (self-control*caffeine interactions, p = 0.525-0.952, η_p^2 = 0.001-0.029) on split time at any point in the time-trial.

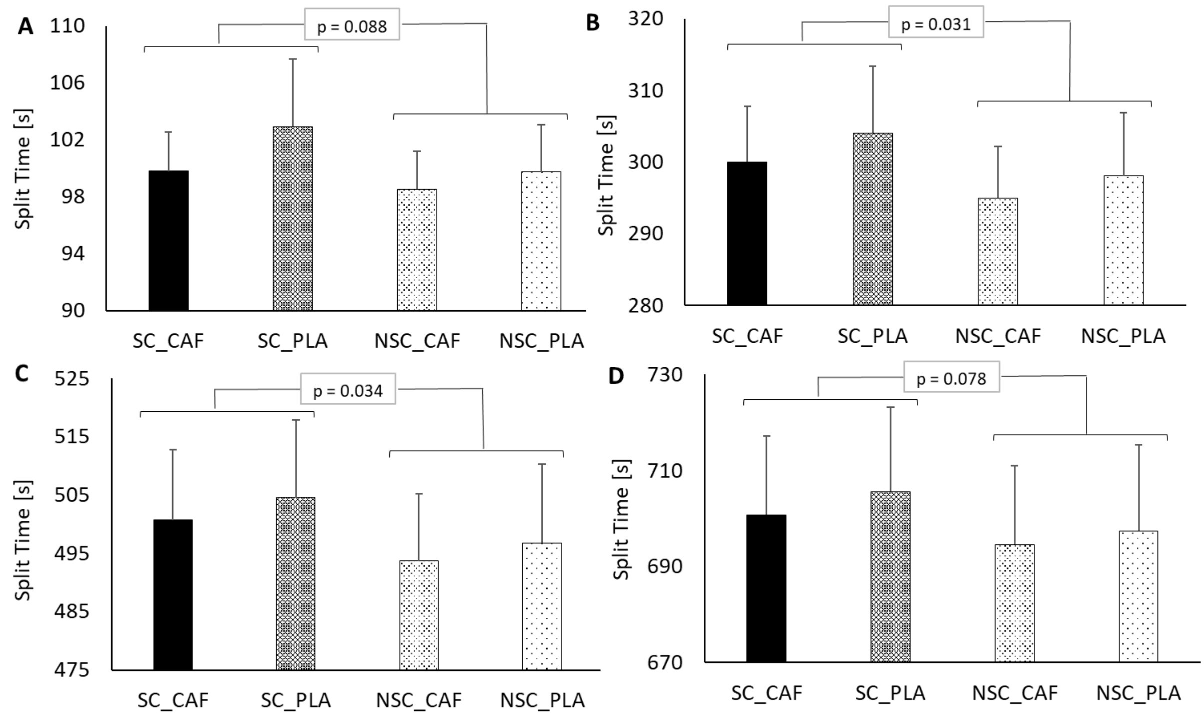

Figure 2: Performance split time at 1 km (A), 3 km (B), 5 km (C) and 7 km (D) of the 10 km time trial. Data are mean ± SEM.
(SC_CAF: self-control exertion with caffeine mouth rinse; SC_PLA: self-control exertion with placebo mouth rinse; NSC_CAF: non-self-control depletion with caffeine mouth rinse; NSC_PLA: non-self-control with placebo mouth rinse)

Perceptions of pain, motivation, and task importance

Overall, there was no three-way (self-control*caffeine*split time) interaction for participant perceptions of pain ($F_{(5,70)}$ = 1.4, p = 0.236, η_p^2 = 0.091), motivation ($F_{(5,70)}$ = 1.2, p = 0.309, η_p^2 = 0.080) or task importance ($F_{(5,70)}$ = 0.8, p = 0.544, η_p^2 = 0.055). There was also no effect of self-control exertion (main effect of self-control; pain: $F_{(1,14)}$ = 0.8, p = 0.400, η_p^2 = 0.051; motivation: $F_{(1,14)}$ = 0.1, p = 0.737, η_p^2 = 0.008; task importance: $F_{(1,14)}$ = 0.2, p = 0.691, η_p^2 = 0.012) or the caffeine mouth rinse (main effect of caffeine; pain: $F_{(1,14)}$ = 0.2, p = 0.635, η_p^2 = 0.017; motivation: $F_{(1,14)}$ = 1.8, p = 0.197, η_p^2 = 0.116; task importance: $F_{(1,14)}$ = 2.6, p = 0.179, η_p^2 = 0.204) on perceptions of pain, motivation or task importance.

Furthermore, there was no effect of self-control exertion or the caffeine mouth rinse on participant perceptions of pain (main effect of self-control: p = 0.153-0.683, η_p^2 = 0.012-

0.140; main effect of caffeine: p = 0.139-0.894, η_p^2 = 0.001-0.150), motivation (main effect of self-control: p = 0.505-0.879, η_p^2 = 0.002-0.032; main effect of caffeine: p = 0.123-0.932, η_p^2 = 0.001-0.162), or task importance (main effect of self-control: p = 0.176-0.972, η_p^2 = 0.001-0.127; main effect of caffeine: p = 0.133-0.506, η_p^2 = 0.035-0.154) at any of the split times (1 km, 3 km, 5 km, 7 km and 9 km) or upon completion of the time-trial. Furthermore, there was no interaction between self-control exertion and the caffeine mouth rinse for pain (p = 0.108-0.341, η_p^2 = 0.065-0.140), motivation (p = 0.404-0.961, η_p^2 = 0.001-0.050), or task importance (p = 0.380-0.930, η_p^2 = 0.001-0.055). Perceived pain, motivation, and task importance data across the trials are shown in table 2.

Table 2: Pain, motivation, task importance and rating of perceived exertion (RPE) across the trials (data are mean ± SEM)

		Self-control exertion with caffeine mouth rinse	Self-control exertion with placebo mouth rinse	Non-self-control exertion with caffeine mouth rinse	Non-self-control exertion with placebo mouth rinse
Pain	1 km	0.6 ± 0.3	0.5 ± 0.1	0.5 ± 0.2	0.8 ± 0.2
	3 km	1.9 ± 0.4	2.1 ± 0.3	2.0 ± 0.5	1.8 ± 0.4
	5 km	2.8 ± 0.4	3.4 ± 0.5	3.0 ± 0.5	3.0 ± 0.6
	7 km	3.4 ± 0.5	4.4 ± 0.6	3.6 ± 0.5	3.9 ±0.5
	9 km	4.9 ± 0.7	5.5 ± 0.6	4.8 ± 0.6	4.8 ± 0.6
	10 km	5.7 ± 0.7	6.3 ± 0.6	5.5 ± 0.7	5.6 ± 0.6
Motivation	1 km	8.7 ± 0.5	8.4 ± 0.4	8.9 ± 0.3	8.5 ± 0.5
	3 km	8.4 ± 0.4	8.6 ± 0.3	8.6 ± 0.3	8.5 ± 0.4
	5 km	8.3 ± 0.4	7.9 ± 0.4	8.4 ± 0.4	8.1 ± 0.5
	7 km	7.9 ± 0.4	7.5 ± 0.5	7.8 ± 0.5	7.7 ± 0.4
	9 km	7.6 ± 0.6	7.1 ± 0.7	7.4 ± 0.6	7.2 ± 0.6
	10 km	7.5 ± 0.8	6.9 ± 0.8	7.2 ± 0.7	7.2 ± 0.7
Task importance	1 km	9.0 ± 0.3	8.8 ± 0.3	9.1 ± 0.3	9.0 ± 0.3
	3 km	8.6 ± 0.3	8.5 ± 0.3	8.8 ± 0.3	8.5 ± 0.4
	5 km	8.3 ± 0.4	8.2 ± 0.4	8.3 ± 0.4	8.2 ± 0.5
	7 km	8.0 ± 0.4	7.5 ± 0.5	7.9 ± 0.5	7.7 ± 0.4
	9 km	7.7 ± 0.6	7.2 ± 0.6	7.7 ± 0.6	7.4 ± 0.6
	10 km	7.3 ± 0.8	7.0 ± 0.8	7.1 ± 0.7	7.3 ±0.7
RPE	1 km	10 ± 0	10 ± 1	10 ± 0	10 ± 0
	3 km	12 ± 0	12 ± 1	12 ±0	12 ± 0
	5 km	14 ± 0	14 ± 1	14 ± 0	14 ± 0
	7 km	15 ± 0	15 ± 1	16 ± 0	16 ± 0
	9 km	17 ± 1	17 ± 1	17 ±1	17 ± 1
	10 km	19 ± 0	18 ± 0	19 ± 0	18 ± 1

RPE, heart rate, and blood lactate concentration

Overall, there was no three-way (self-control*caffeine*split time) interaction for RPE ($F_{(5,70)}$ = 0.2, p = 0.954, η_p^2 = 0.015), heart rate ($F_{(5,70)}$ = 0.9, p = 0.481, η_p^2 = 0.085) or blood lactate concentration ($F_{(6,66)}$ = 0.2, p = 0.969, η_p^2 = 0.020). There was also no effect of self-control exertion on RPE (main effect of self-control, $F_{(1,14)}$ = 0.1, p = 0.742, η_p^2 = 0.008) or heart rate (main effect of self-control, $F_{(1,14)}$ = 0.3, p = 0.585, η_p^2 = 0.031). However, there was a tendency for blood lactate concentration to be higher on the non-self-control trials (main effect of self-control, $F_{(1,11)}$ = 3.5, p = 0.090, η_p^2 = 0.240). There was no effect of the caffeine mouth rinse on RPE, heart rate or blood lactate concentration (main effect of caffeine; RPE: $F_{(1,14)}$ = 0.1, p = 0.951, η_p^2 = 0.001; heart rate: $F_{(1,14)}$ = 0.1, p = 0.979, η_p^2 = 0.001; lactate: $F_{(1,11)}$ = 0.1, p = 0.727, η_p^2 = 0.012).

Furthermore, when considering RPE and heart rate at each time point separately (1 km, 3 km, 5 km, 7 km, 9 km and 10 km), there was no effect of self-control exertion (main effect of self-control; RPE: p = 0.342-0.999, η_p^2 = 0.001-0.065; heart rate: p = 0.253-0.868, η_p^2 = 0.003-0.086), the caffeine mouth rinse (main effect of caffeine; RPE: p = 0.150-0.999, η_p^2 = 0.001-0.142; heart rate: p = 0.328-0.921, η_p^2 = 0.001-0.074), nor an interaction between self-control manipulation and caffeine (self-control*caffeine interaction; RPE: p = 0.719-0.999, η_p^2 = 0.001-0.028; heart rate: p = 0.389-0.669, η_p^2 = 0.017-0.068).

There was no difference between the trials for blood lactate concentration at baseline (main effect of self-control, $F_{(1,12)}$ = 0.3, p = 0.591, η_p^2 = 0.025; main effect of caffeine, $F_{(1,12)}$ = 1.1, p = 0.322, η_p^2 = 0.082; self-control*caffeine interaction, $F_{(1,12)}$ = 0.1, p = 0.929, η_p^2 = 0.001). Blood lactate concentration was higher at the 1 km stage of the time trial on the non-self-control trials compared to the self-control exertion trials (self-control: 2.83 ± 0.29 $mmol \cdot L^{-1}$, non-self-control: 3.09 ± 0.34 $mmol \cdot L^{-1}$; main effect of self-control, $F_{(1,14)}$ = 5.2, p = 0.038, η_p^2 = 0.271). However, there was no difference at any of the remaining time points between the self-control exertion and non-self-control exertion trials (main effect of self-control, p = 0.106-0.591, η_p^2 = 0.025-0.186), nor was there an effect of the caffeine mouth rinse at any time point (main effect of caffeine, p = 0.322-0.990, η_p^2 = 0.001-0.082). Self-control exertion and the caffeine mouth rinse did also not interact to affect blood lactate concentration (self-control*caffeine interaction, p = 0.361-0.929, η_p^2 = 0.001-0.060).

Discussion

The present study explored the effects of exerting self-control on a subsequent endurance task in well-trained individuals, and the potential for a caffeine mouth rinse to attenuate any decrements in performance due to self-control exertion. The main finding of the present study was that the effects of exerting self-control on subsequent endurance performance are dependent on the timing of performance inspection. Exerting self-control led to slower performance during the early stages (up to and including the 7 km split time) of the endurance cycling task. By the end of the time-trial, however, there was no effect of self-control exertion on overall performance time. Furthermore, caffeine mouth rinsing did not attenuate the effects of self-control exertion on subsequent endurance performance. The findings provide new evidence that prior self-control exertion may interfere with pacing strategies during subsequent endurance performance.

A novel finding of the present study was that self-control exertion affects pacing strategies during the first 7 km of a 10 km cycling time-trial. This is in accordance with previous research (e.g., Boat et al., 2017; Wagstaff, 2014), with the present study extending these findings to show that engaging in an initial task that required self-control resulted in the selection of a slower pace in the early stages of endurance performance (i.e., in the first 7 km of the cycling time-trial). This was supported by a lower blood lactate concentration on the self-control exertion trials, indicative of the lower self-selected exercise intensity during the early stages of the cycling task. However, in the latter stages of the time-trial (i.e., the final 3 km), the pacing intensity increased, leading to no differences in overall performance time. In line with many theories of self-control (Baumeister et al., 1998; Inzlicht & Schmeichel, 2016), prior self-control exertion led to decreased self-control in the subsequent cycling task, manifesting as being unable or unwilling to self-regulate pacing in the early stages of the performance task, rather than a slower performance time overall.

Despite affecting pacing strategies, prior self-control exertion did not affect overall 10 km cycling time-trial performance, despite confirmation that the manipulation of self-control (via the CR10 scale and Stroop test performance) was successful. This is contrary to previous findings where prior self-control exertion has reduced performance on subsequent physical tasks requiring self-control, such as press-up, wall-sit, and cycling tasks (e.g., Boat & Taylor, 2017; Dorris et al., 2012; Englert & Wolff, 2015). One possible explanation may be related to the feedback that participants received towards the end of the cycling task. In many of the aforementioned self-control studies, participants have received no encouragement or information throughout the physical performance tasks. In the current study, the participants received a signal at 8 km and 9 km completion of the time-trial, to inform them that they had 2 km and 1 km of the time-trial remaining. It is possible that this feedback statement reminded the participants of their motivation for their distal goal (i.e., persisting on the cycling task to optimize performance time) and helped them to resist competing, proximal, temptations (i.e., reducing exercise intensity to minimize muscle discomfort; Milyavskaya & Inzlicht, 2018). Although exerting self-control to overcome the pain and discomfort during the endurance task will be required at some stage for optimal performance, the provision of the feedback statements at 8 km and 9 km may have reinforced the value of the distal goal of optimizing performance. This explanation remains speculative at present. However, intervention strategies that target motivation during subsequent physical tasks by reinforcing the value of distal goals, or decreasing the worth of indulging in competing proximal goals, may reduce the effects of prior self-control exertion on subsequent physical performance. This is a potential avenue for future research in this area. Alternatively, from a resource model perspective (Baumeister et al., 1998), it is possible that self-control resources replenished during the latter stages of the cycling time-trial, leading to performance differences disappearing towards the end of the endurance task.

Another key finding of the present study was that in a well-trained population, perceptions of pain, motivation, task importance, and ratings of perceived exertion were unaffected by prior self-control exertion. This finding in well-trained populations in the present study is contrary to findings in recreationally active participants in previous research (e.g., Boat & Taylor, 2017; Boat et al., 2018). One possible explanation may be that in expert populations, the persistent pursuit of the same cognitive goal leads to the automatization of cognitive processes (Williams et al., 2009). When this occurs, self-control resources may not be required to the same extent as conscious self-control (Schmeichel & Baumeister, 2004), in novice performers. From a shifting priorities perspective (Inzlicht & Schmeichel, 2016), the initial exertion of self-control may not have caused attentional and motivational foci to shift because conscious self-control was not required (Baumeister & Bargh, 2014; Englert, 2019). The undertaking of further mechanistic work could be instrumental to determine whether prior self-control exertion leads to shifts in attentional and motivational focus in well-trained populations; and the implications of this for exercise performance.

The findings of the present study suggest that a caffeine mouth rinse does not affect 10 km cycling time-trial performance, nor does it attenuate the effects of prior self-control exertion on pacing strategies. The present study extends previous work suggesting that a caffeine mouth rinse does not affect sprint-cycling performance in well-trained cyclists (e.g., Doering et al., 2014). Whilst previous studies have found a beneficial effect of a caffeine mouth rinse during a 30 minute self-selected cycling task (Bottoms et al., 2014), the present study suggests that such ergogenic effects do not exist in an ecologically valid cycling time-trial. It is also possible that the mouth-rinse protocol used in the current study may not be suitable to elicit such a response from caffeine exposure in the mouth. For instance, caffeine delivered via chewing gum for a 5 min duration has been found to produce ergogenic effects on sprint cycling performance (Paton, Lowe, & Irvine, 2010). It could be that the longer duration of the presence of caffeine in the oral cavity with caffeine chewing gum leads to greater antagonism of adenosine receptors, and thus a beneficial effect on exercise performance (Ribeiro & Sebastiao, 2010; Rubinstein et al., 2001). Moreover, a further novel finding of the present study was that the caffeine mouth rinse did not affect attentional and motivational shifts following self-control exertion. Given that the present study is the first to examine a caffeine mouth rinse following self-control exertion, future research is required to examine the impact of a caffeine mouth rinse (or chewing gum) in recreationally active participants where shifts in attentional processes have been suggested to influence exercise performance (e.g., Boat & Taylor, 2017; Boat et al., 2018).

Limitations and future directions

It is important to address some potential limitations of the current study. For example, it is important to acknowledge that the Stroop task is not sport specific, and is relatively artificial in nature (Englert, 2016). In the current study, however, it was imperative to utilize a well-established self-control task in a controlled setting. The Stroop task has been successfully used in self-control studies previously (e.g., Boat & Taylor, 2017; McEwan et al., 2013). Nonetheless, future studies could apply sport-specific measures to deplete self-control to make findings more relevant to sport practitioners.

In addition, biomarkers of physical capacity (e.g., maximal oxygen uptake), and bio-chemical testing to confirm adherence to pre-trial restrictions (e.g., not to consume alcohol 24 hours before testing, replication of dietary intake) were not assessed. Such biomarkers could be included in future studies to provide valuable descriptive measures of the participants and to facilitate comparisons between studies, whilst confirmation of adherence to pre-trial restrictions in future research would enhance the experimental control. Furthermore, as in many mouth rinse studies of this nature, the rinse solution was not a pure caffeine rinse and was instead diluted with flavourings. Therefore, it is not possible to exclude the potential for the substances to interact to affect performance. However, the flavouring is required in caffeine mouth rinse studies to ensure that the caffeine and placebo rinse solutions are taste matched. In addition, it is important to note, that although the participants performed the experimental sessions at the same time of day, experimental trials were not always performed on the same day of the week.

Although the findings of the current study do not support the tenants of the shifting priorities model (Inzlicht & Schmeichel, 2016), further research should manipulate the length of the second task (i.e., time-trials of different lengths) and examine the effects of prior self-control exertion on subsequent endurance performance in an expert population. It could be that the effects of self-control exertion become more pronounced in performance tasks lasting considerably shorter (as evidenced by the alteration of pacing strategies in the first 7 km of the cycling time-trial in the present study) or longer. In addition, the current study examined the attentional and motivational tenants of the shifting priorities model of self-control (Inzlicht & Schmeichel, 2016; Milyavskaya & Inzlicht, 2018). However, according to this theory, following a primary self-control task, individuals may also experience shifts in emotions during a subsequent task, also requiring self-control (e.g., 10 km cycling time-trial). Future research should make efforts to explore whether the exertion of self-control leads to a shift in emotion during subsequent tasks (Inzlicht & Schmeichel, 2012). Also, participants' self-efficacy was not assessed following the Stroop task in the current study. It has been argued that self-control depletion leads to reductions in self-efficacy, which may account for the reductions in performance on a subsequent endurance task (Graham & Bray, 2015). Therefore, task self-efficacy should be further investigated as a psychological factor that may explain performance reductions following self-control exertion.

Finally, it is possible that spending longer on the initial self-control task could consume more resources or decrease motivation, and subsequently the magnitude of the deleterious effect on performance may be greater. Further research should manipulate initial task duration in a sequential-task paradigm and examine its effect on performance during the second task (Lee, Chatzisarantis, & Hagger, 2016; Wolff et al., 2019). Such knowledge may help to inform the designing and evaluation of future experiments exploring self-control exertion and subsequent physical performance, and may help to resolve the ongoing debate concerning the size of the depletion effect (Lee et al., 2016; Wolff et al., 2018), and the underlying mechanisms of the effect.

Conclusion

The findings of the present study imply that prior self-control exertion affects self-regulatory pacing strategies during subsequent endurance performance, in well-trained individuals. Furthermore, the present study provides important novel findings that prior self-control exertion does not lead to shifts in attention and motivation on subsequent physical endurance tasks in expert populations. Finally, caffeine mouth-rinsing does not attenuate the effects of self-control exertion on subsequent endurance performance.

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