Self-control exertion and glucose supplementation prior to endurance performance

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Abstract

Objectives

Completion of a task requiring self-control may negatively impact on subsequent self-regulatory efforts. This study explored a) whether this effect occurs during a well-practiced endurance task, b) the potential for glucose supplementation to moderate this effect, and c) whether this effect differed over time.

Method

Fourteen trained cyclists completed four simulated 16 km time trials on an electromagnetically braked cycle ergometer. Prior to each time trial, participants completed a congruent Stroop task or an incongruent Stroop task that required self-control. They also received either a glucose-based drink or placebo. Participants' performance time and heart rate were recorded throughout the time trials.

Results

Multilevel growth curve analysis revealed a significant three-way interaction between self-control, glucose, and time (b = -0.91; p = 0.02). When participants did not exert self-control (congruent Stroop) or consume glucose (placebo drink) they were slowest during the early stages of the time trial but quickest over the full distance. No differences were found in heart rate across the four conditions.

Conclusions

Findings suggest that pacing may explain why self-control exertion interferes with endurance performance. Moreover, the debate revolving around depletion of self-control must consider that any observed effects may be dependent on the timing of performance inspection.

Keywords: Growth models, cycling, self-regulation, ego depletion

Self-control exertion and glucose supplementation prior to endurance performance

Self-control alludes to any effort to amend one's own inner states or responses, including actions, feelings, thoughts, and task performances (Baumeister, Vohs, & Tice, 2007). This process facilitates desirable behavior by helping to resist inappropriate impulses and continuing with appropriate behavior. Self-control is important for sport performance because athletes are required to control their cognitive, emotional, and motor processes for superior athletic performance (Englert & Bertrams, 2012; Wagstaff, 2014). For example, athletes are required to resist discomfort and the urge to slow during sustained aerobic performance with the goal of producing the fastest time possible. Self-control ability can vary between individuals meaning that some individuals are generally better at self-control than others (i.e., trait self-control), as well as within individuals between situations (i.e., state self-control; Tagney, Baumeister, & Boone, 2004). For instance, some researchers suggest that the capacity to exert self-control is limited and becomes diminished when an individual regulates his or her behaviors, a state known as ego depletion (Baumeister et al., 2007). Consequently, the individual will have a reduced capacity to perform any subsequent behavior that requires self-regulation. This 'limited resource' perspective has received both meta-analytic support (Hagger, Wood, Stiff, & Chatzisarantis, 2010) and fervent challenge (e.g., Carter, Kofler, Forster, & McCullough, 2015; Hagger et al., 2016; Kurzban, 2016). Other researchers propose that self-control exertion is accompanied by shifts in motivation, emotion, and attention, and discount the limited resource explanation (Inzlicht & Schmeichel, 2012). When participants are confronted with a second self-control task, participants may be less motivated to comply with task-relevant goals (unless they receive incentives to do so).

Irrespective of the different explanations, considerable evidence exists that performance on subsequent physical tasks is reduced following an initial task requiring self-control. For example, individuals who were asked to regulate their emotions while watching an upsetting movie were unable to sustain an isometric handgrip squeeze for as long as individuals who watched the movie but engaged in no emotion regulation (Muraven, Tice, & Baumeister, 1998). Although squeezing a handgrip primarily requires muscular strength, overcoming fatigue and overriding the urge to quit are acts of self-regulation. The ability for cognitive or emotion regulation to impair subsequent handgrip performance has been corroborated (e.g., Bray, Graham, Martin Ginis, & Hicks, 2011). Building on this work, researchers have attempted to enhance the ecological validity of the evidence so that conclusions regarding more complex human performance can be drawn. A variety of tasks requiring self-control (e.g., counting backwards from 1000 in multiples of seven while holding a spirit level, transcribing a neutral text whilst omitting the letters ‘e’ and ‘n’, completing an incongruent Stroop task, supressing emotions during an upsetting movie) have been associated with reduced performance in press-up tasks, basketball free-throw tasks, and cycling performance (Dorris, Power, & Kenefick, 2012; Englert & Bertrams, 2012; Englert & Wolff, 2015; Wagstaff, 2014).

Collectively, the studies above provide valuable insight into self-regulatory processes and athletic performance. However, it is currently unknown whether previous exertion of self-control impairs subsequent endurance performance when self-regulation is potentially automatic. In expert populations, the persistent pursuit of the same cognitive goal results in the automatization of cognitive processes (Williams, Huang, & Bargh, 2009), therefore, self-regulatory resources may not be required to the same extent as conscious self-regulation (Schmeichel & Baumeister, 2004). However, successful endurance performance involves considerable levels of discomfort and overcoming these demands may exacerbate the need for conscious self-regulation. As a result, even in an expert population, engaging in an initial task requiring self-control is likely to impair subsequent endurance performance because the self-regulation required to maintain effort and resist discomfort is salient.

As well as exploring the salience of self-control during well-practiced human performance, the present study aims to examine whether glucose can attenuate any decrements in performance due to prior self-control exertion. Tasks requiring controlled, effortful self-control demand increased cerebral functioning, possibly causing a concomitant rise in the requirement for blood glucose in the brain (Gailliot et al., 2007). Glucose in the blood is often measured under the assumption that equilibrium exists between glucose in the blood and the brain (Lund-Anderson, 1979). Glucose ingested immediately before and/or during exercise is rapidly digested, absorbed, and available for oxidation (Jeukendrup et al., 1999). Hence, glucose drinks may be a viable means of increasing the amount of glucose available for self-regulatory tasks, providing that one allows time for the glucose to reach the blood stream. Indeed, replenishing glucose with a drink containing sugar has been shown to restore performance during cognitive tasks that require self-control (DeWall, Baumeister, Gailliot, & Maner, 2008; Gailliot et al., 2007; Wang & Dvorak, 2010). In a meta-analysis, the effect of experimental glucose supplementation on the depletion effect was deemed to be large and homogeneous (d = 0.75; Hagger et al., 2010).

Although the evidence seems compelling, the role of glucose in counteracting self-control depletion has come under robust criticism. In a recent study that employed a selective attention task (delay discounting) as the self-control manipulation and dependent measure, glucose administration did not moderate the depleting effect (Lange & Eggert, 2014). Similar results were also observed following an emotionally upsetting video (versus an emotionally neutral video; Dvorak & Simons, 2009), as well as a go/no-go paradigm (versus an infrequent no-go paradigm; Lange, Seer, Rapior, Rose, & Eggert, 2014). It is possible that the exhaustion of self-control resources is moderated by glucose consumption only when dissimilar tasks are utilized as experimental manipulation and dependent variable measure (DeWitte, Bruyneel, & Geyskens, 2009). Engaging in two similar acts, like the design of

Lange and Eggert's (2014) experiment, has been argued to allow cognitions or affective experiences concerning the primary self-control task to influence effort on the second self-control task and mask potential effects of glucose consumption (Chatzisarantis & Hagger, 2015a; 2015b; Wallace & Baumeister, 2002). Athletic endurance performance represents an interesting context to pursue this research agenda given the critical role played by glucose drinks in optimizing athletic performance (e.g., Jeukendrup, 2010). Sports drinks are so popular that their value is estimated to reach $2billion by 2016 in the United States alone (International Markets Bureau, 2010). It is significant, therefore, to investigate the moderating role of glucose supplementation on self-control exertion and subsequent athletic endurance performance. Understanding potential psychological effects of glucose supplementation on endurance performance (as opposed to well-researched physiological processes) would advance our understanding of human behavior during conditions of fatigue (e.g., Hagger & Chatzisarantis, 2012; Molden et al., 2012).

Extending the literature described above, the aims of the current research were to determine a) whether exerting self-control reduces endurance performance in well-trained individuals, b) the potential for glucose administration to attenuate any decrements in performance due to prior self-control exertion, and c) whether any observed effects are variable over different stages of endurance performance. We also examined heart rate because equivocal findings have been seen previously (Englert & Wolff, 2015; Marcora, Staiano, & Manning, 2009; Wagstaff, 2014). The latter aim of the study is particularly important as the various theoretical debates in the self-control literature have not appropriately considered the timing of performance inspection. As an initial insight to this point, Englert and Wolff (2015) reported that the deleterious effect of self-control exertion on cycling performance became more pronounced over time. Building on this work, the present study aimed to explore whether any effects of self-control exertion and/or glucose administration persist or change over the course of a subsequent endurance task.

In the present experiment, our initial task to manipulate self-control requirements was a congruent versus incongruent Stroop task carried out for four minutes. This task has been shown to require self-control (McEwan, Martin Ginis, & Bray, 2013) and has been successfully employed for the same length of time in previous research (i.e., four minutes; Hagger et al., 2010). To measure athletic performance we used a 16 km laboratory-based cycling time trial. This endurance task requires numerous self-regulation behaviors, including the inhibition of aversive feelings, such as physical pain and thermal discomfort, the urge to quit, as well as the regulation of attention and emotion throughout periods of physical stress (Martin et al., 2016; Marcora et al., 2009). Further, a time trial protocol may have greater ecological validity than time to exhaustion protocols often used in previous research (e.g., Carter, Jeukendrup, & Jones, 2005), because performance and physiological responses are similar compared to outdoor time trials (Currell & Jeukendrup, 2008). Finally, a 16 km distance is familiar and well-practiced by cyclists; therefore, it may reduce the need for conscious self-regulation (Schmeichel & Baumeister, 2004).

Based on the broad self-control literature (e.g., Bray et al., 2011; Englert & Wolff, 2015; Wagstaff, 2014) it was hypothesized that engaging in a cognitively demanding task previously shown to require self-control (i.e., an incongruent Stroop task) would result in poorer performance on a 16 km cycling time trial, compared to a cognitively simple task (i.e., a congruent Stroop task). No significant difference in heart rate during the cycling task following the exertion of self-control was expected. Although differences in heart rate have been observed previously (Englert & Wolff, 2015; Wagstaff, 2014), we align this hypothesis with research ruling out cardiovascular explanations for performance reductions following self-control exertion (Marcora et al., 2009). We hypothesized that glucose drink supplementation would attenuate any reductions in performance due to self-control exertion, compared to a placebo drink (DeWall et al., 2008, Wang & Dvorak, 2010). Finally, we hypothesized that any effects of self-control exertion and glucose would be more pronounced as time progresses (Englert & Wolff, 2015; Jeukendrup, Hopkins, Aragon-Vargas, & Hulston, 2008).

Method

Participants

Fourteen endurance trained cyclists (4 female, 10 male) aged 20-52 years old took part in the study. Inclusion criteria required that participants had experience in competitive cycling-based events (e.g., triathlon, road cycling), and were currently training for a cycling event. The participants had, on average, five years (*SD* = 6 years) competitive experience, and spent, on average, 11 hours (*SD* = 6 hours) per week training. All participants were healthy, as assessed by a university approved general health questionnaire. Due to our choice of longitudinal growth modeling as our analytic strategy (see Data Analysis below), conventional criteria regarding sufficient sample sizes in single level designs (e.g., repeated measures analysis of variance) are irrelevant. Indeed, growth models typically offer greater statistical power than traditional methods applied to the same data (B. O. Muthén & Curran, 1997) because the relevant unit of measurement are the repeated observations, not the participant (in this study, the 675 measurements throughout the time trials; Singer & Willett, 2003). What constitutes an adequate sample size for longitudinal growth model is debatable (Curran, Obeidat, & Losardo, 2010), however, modeling of artificial data revealed that estimated power to detect a small-moderate interaction effect (Effect Size = .30) with five measurement points (we had 15) and 675 total observations would be > .90 (B. O. Muthén & Curran, 1997). In view of this, we deem our sample size acceptable.

Procedures

Following approval from a university ethics committee, each participant gave written informed consent after the study was explained in full and it was clarified that involvement was anonymous and voluntary.

Preliminary fitness test. At least one week before the experimental trials began participants completed an incremental-effort cycle test to volitional exhaustion to determine individuals' maximal power output (Wmax). This test was completed on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) with adjustable saddle height and handle bar position. Following a self-selected warm up, participants began cycling at 95 W for three minutes, followed by incremental steps of 35 W every three minutes until exhaustion. Heart rate was monitored throughout by a radiotelemetry heart rate monitor (Polar Vantage NV, Kempele, Finland). Wmax was calculated from the final completed work rate plus the fraction of time spent in the final non-completed work rate, multiplied by 35 W. Eighty-five percent Wmax was subsequently used in all cycling time trials. During this test only, verbal encouragement was given to the participants by the same investigator. These procedures have been advocated and frequently employed in athletic endurance research (e.g., Jeukendrup et al., 2008).

Experimental protocol. Participants were instructed to keep a record of their food intake and activity patterns on the day before the first time trial and to replicate the same diet and exercise activities 24 hours before all subsequent trials. They were also asked to refrain from strenuous exercise and avoid alcohol and caffeine intake 24 hours before the start of each trial.

Each participant took part in four experimental sessions. An individual's self-control strength is likely reduced on stressful days, relative to days that were not stressful (Englert & Rummel, 2016; Tangney et al., 2004). Therefore, it was important to control for the influence of daily stress in the current study. On arrival in the laboratory, participants completed the seven stem questions from the Daily Inventory of Stressful Events Questionnaire (Almeida, Wethington, & Kessler, 2002). Participants were instructed to indicate whether any of a number of stressful events had occurred today by circling either ‘yes’ or ‘no’ (e.g., “An argument or disagreement with someone”). The items have demonstrated acceptable internal consistency and predictive validity in previous research (Almeida et al., 2002).

Participants were then fitted with the heart rate monitor and the cycle ergometer was adjusted to a comfortable position as requested by the participant. Participants began a standardized warm-up consisting of 10 minutes at 50% Wmax, followed by five minutes at 60% Wmax. Immediately following the warm-up participants were required to complete either a self-control or non-self-control experimental manipulation. A modified Stroop task was used as the experimental manipulation in this study. This task has been utilized as a means of depleting individuals’ self-control strength in many laboratory studies of self-regulation (e.g., Hagger et al., 2010). In this task, participants are presented with color words and required to read aloud the color of the print ink and ignore the text for each word presented. However, when participants encounter a word presented in red ink, they are required to override the general instructions and read aloud the printed word. In the self-control condition, the print ink colour and printed text were mismatched. For example, the word ‘blue’ printed in yellow – the correct verbal response in this case would be yellow. However, when the word ‘blue’ is presented in red ink, the correct verbal response would be blue. Previous studies have repeatedly shown that this task is cognitively challenging and require self-control because individuals have to volitionally override their primary impulse of naming the word instead of the font colour (e.g., McEwan et al., 2013). In the non-self-control condition, the words were matched (e.g., the word ‘blue’ is printed in blue ink, ‘red’ is printed in red ink) and verbally communicating the color of the ink does not require self-control (Baumeister et al., 2007). Participants performed the Stroop task on a computer for four minutes whilst sitting in a quiet room, words were serially presented on the screen with a 1,500 ms interval. Participants were instructed to respond as accurately as possible.

The glucose experimental manipulation took place immediately after the Stroop task. Participants ingested an initial bolus of 300 ml of a 3.9% glucose-electrolyte solution (Powerade) or a placebo solution (Powerade; zero glucose) containing flavourings, sweeteners, and electrolytes. The two drinks were similar in taste, texture, color, and electrolyte content.

Immediately after the drink consumption, participants commenced a simulated 16 km cycle time trial. In these time trials, participants completed a predetermined amount of work as fast as possible. The amount of work to be performed was calculated by assuming that participants could cycle at 85% of their Wmax for 25 min, which is comparable to 16 km personal bests of cyclists on the road (Jeukendrup et al., 2008). The ergometer was set in the pedalling-dependent mode (i.e., power varies with cadence) so as to replicate as accurately as possible a time trial in a field setting. When half the workload had been completed, participants consumed a further 200 ml of either glucose solution or placebo solution (depending on experimental condition). This was to ensure that glucose (or placebo) was available in the blood stream throughout the latter part of the time trial. Outcome variables were heart rate and time, which were recorded after every 10% of the time trial had been completed, as well as 92.5%, 95%, and 97.5% completion. Participants received no encouragement or information except a signal that they had 20% and 10% of the time trial remaining. Music and external distracting material was eliminated during all exercise trials. All exercise trials were completed under normal and standard 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.

In sum, participants completed four simulated 16 km time trials under four experimental conditions: self-control/glucose, self-control/placebo, non-self-control/glucose, and non-self-control/placebo. Conditions were counterbalanced. Trials were separated by seven days and always performed at the same time of day to prevent any circadian variance.

Data analysis

Study hypotheses were investigated using multilevel growth models employing MLwiN 2.26 software (Rasbash, Steele, Browne, & Goldstein, 2012). Growth models examine variability in intra-individual patterns of change over time (Singer & Willett, 2003), therefore, they are particularly suited to measuring differences in time-trial performance. This type of analysis provides greater flexibility compared to traditional analysis of variance, in particular allowing for missing data points, unequally spaced time points, time-varying covariates, and non-normally distributed repeated measures (Curran et al., 2010). By using multilevel modeling we were able to construct separate, but associated equations to model time-varying (e.g., performance and heart rate) and time-invariant variables (e.g., experimental condition), which leads to superior estimation of parameters and statistical significance (Hox, 2010; Singer & Willet, 2003). Two levels of analysis were specified. Level 1 constituted the repeated observations throughout the time trials, which comprised Level 2 in the analysis (see Quene & Bergh, 2004 for a similar design). The 14 participants could have constituted a third level, however, this would represent an insufficient number of higher level units. The sample size at Level 1 was 675 data points because some trials had missing data, however, multilevel modeling does not require complete data sets (Hox, 2010) and deletion of participants with incomplete data has been strongly argued against (Newman, 2009).

Prior to including predictor variables in the models, we first constructed intercept only models to establish the proportion of variance at both levels of analysis for performance (model 1a) and heart rate (model 1b). Building on these models we then included a series of predictor variables to test our study hypotheses. First, we included linear time as a variable to model change in the outcome variable over the course of the time trial. Time was centred at the end of the time trial (i.e., the end of the time trial was labelled zero, with decreasing values towards the beginning of the time trial). We then included the two binary coded main effects of the experimental conditions (i.e., self-control/non-self-control and placebo/glucose). Furthermore, we included a three-way interaction term (and associated lower order terms) between time, self-control, and glucose to explore how the effects of experimental condition changed over the course of the trial. We also controlled for daily stress levels of participants in our models which was group mean centered to represent participants' relative daily stress. These models are referred to as 2a (performance) and 2b (heart rate).

Results

Preliminary analysis

Table 1 displays means and standard deviations for performance (time) and heart rate for each experimental condition. Intraclass correlation coefficients (ICCs) were calculated from model 1a and 1b (shown in Table 2). The ICC for performance was 0.00 indicating that 100% of the variance in performance was attributable to the within-person level. The ICC for heart rate was 0.76 indicating that 24% of the variance in heart rate was attributable to the within-person level. The Cronbach alpha coefficient for the Daily Inventory of Stressful Events Questionnaire ranged between .51 - .67 across the four trials.

A repeated measures analysis of variance was conducted to check for order effects. No significant differences were found for time trial performance that were due to ordering of experimental conditions ($F(3, 24) = 1.77$, $p = .18$).

Primary analysis

As shown in Table 2, model 2a revealed a significant main effect for time, as well as significant interaction effects for self-control and time, and glucose and time. However, these were superseded by a significant three-way interaction between self-control, glucose, and time (b = -0.91; p = 0.02). Simple slopes analysis applied to multilevel models (Preacher, Curran, & Bauer, 2006) was subsequently conducted to interpret this interaction (Figure 1). After 10% of the trial had been completed (Figure 1a), there were only small differences in performance time across experimental conditions (as would be expected after only ~3 minutes). However, participants were slowest when they did not exert self-control (congruent Stroop) or consume glucose (placebo drink). Participants were fastest when they did not exert self-control (congruent Stroop) but consumed glucose. At the midpoint of the trial (Figure 1b) participants were now fastest when they did not exert self-control or consume glucose (i.e., the opposite trend, compared to the beginning of the trial). Negligible differences in performance were found in the other three experimental conditions. This trend was repeated at the end of the trial (Figure 1c), with considerably faster performance when participants did not exert self-control or consume glucose, compared to the other three conditions.

Model 2b revealed no significant main effects or interaction effects. In other words, experimental condition did not influence heart rate at any point in the time trial.

Discussion

The present study explored the effects of exerting self-control on a subsequent endurance task requiring self-regulation in well-trained endurance athletes. In this study we demonstrate that the effects of exerting self-control on subsequent endurance performance are dependent on the timing of performance inspection. Exerting self-control, consuming glucose, or a combination of both led to somewhat faster performance during the early stages of endurance cycling performance. By the end of the time trial this trend was reversed; participants completed the time trial in the fastest time when they did not exert self-control or consume glucose. Until now, it was unclear whether the continuous pursuit of the same, well-practiced cognitive goal in well-trained athletes would require sufficient levels of conscious self-regulation to be impaired by previous exertion of self-control.

In accordance with previous research (e.g., Bray et al., 2011; Englert & Wolff, 2015; Wagstaff, 2014) exertion of self-control significantly reduced subsequent performance in a task requiring self-control, in this case cycling time trial performance. However, this could only be concluded if one considers the entire time trial performance. Effects of self-control exertion on endurance performance have been shown to become more pronounced over time in previous work (Englert & Wolff, 2015). In the early stages of time trials in the present study, participants actually went faster when they were previously required to exert self-control relative to the non-self-control/placebo condition. Self-control diminishes over time because exertion becomes increasingly aversive (Kool & Botvinick, 2014), however, enough time needs to elapse for motivational and attentional foci to be shifted from the distal goal (cycling as fast as possible) to the proximal tempting goal (relieving the physiological distress; Milyavskaya & Inzlicht, in press). Examination of performance prior to any shifts taking place may lead to the erroneous conclusion that self-control exertion may actually increase performance, or at least no detrimental effects exist. Time may be particularly important when considering expert performance as initial efforts to self-regulate may be automatic and non-conscious (Schmeichel & Baumeister, 2004; Williams et al., 2009). Irrespective of theoretical stance, endurance tasks like the one employed in the present study would suit the exploration of prior self-control exertion with appropriate consideration of time. For example, researchers could establish when motivational priorities shift (Milyavskaya & Inzlicht, in press), when self-regulation switches from automatic to conscious processes (Schmeichel & Baumeister, 2004), or when self-control resources become too scarce (Gailliot et al., 2007).

Furthermore, in terms of sport performance, our results imply that prior self-control exertion may interfere with self-regulatory pacing strategies (i.e., optimal power output) during subsequent endurance performance (Wagstaff, 2014). Engaging in an initial task that did not require self-control led participants to adopt a pacing strategy that appeared to be more consistent over the course of the endurance task (i.e., optimal self-regulation). In contrast, initial self-control exertion may lead to the selection of a pacing intensity that is too high at the initial phase of endurance performance (i.e., suboptimal self-regulation), leading to reductions in intensity in the latter stages of the trial and decrements in overall endurance performance. It is possible that shifts in attention due to self-control exertion may interfere with self-regulation, but not in the expected way. In line with many theories of self-control, initial self-control exertion may led to decreased self-control in a subsequent task, but this manifested in being unable or unwilling to self-regulate pacing, rather than a slower pace *per se*.

Unlike previous self-control research (e.g., Englert & Wolff, 2015; Wagstaff, 2014), this performance difference could not be explained by changes in heart rate. Rather, the findings are in line with literature on cognitive fatigue reporting no effect on cardiovascular responses during endurance performance following a cognitively demanding manipulation (Marcora et al., 2009). These equivocal findings are not easily explained. The duration of the self-control task and the endurance task in the present study were arguably more aligned with studies that did find a difference in heart rate. Equally, there seems no obvious pattern when inspecting fitness of athletes, time trial protocol, or experimental design across the studies. Clarification of this potential explanation for reductions in performance is critical to move forward, at the very least to elucidate whether individuals put forth less effort following self-control exertion (Englert & Wolff, 2015; Wagstaff, 2014) or *perceive* that more effort is required following self-control exertion (Marcora et al., 2009).

On the basis of some previous research (DeWall et al., 2008; Hagger et al., 2010; Wang & Dvorak, 2010), we also hypothesized that glucose supplementation would moderate any effects of self-control exertion on subsequent performance. We did not find support for this hypothesis. In fact, ingesting glucose led participants to cycle at a slightly faster pace in the early stages but overall performance was slower, compared to the non-self-control/placebo condition. Glucose intake during tasks of this intensity and duration may be ineffective because any ergogenic effects on the central nervous system may be overridden by increased metabolic stress and afferent feedback (Jeukendrup et al., 2008). The lack of moderating effect of glucose concurs with the conclusions made by other researchers (e.g., Lange & Eggert, 2014). Indeed our results suggest that, in this endurance performance-based paradigm, ingesting glucose may lead to similar interference with pacing strategies to that of self-control exertion described previously. This represents a thought-provoking idea as oral exposure to glucose has been associated with activation of areas of the brain (e.g., anterior cingulate cortex) responsible for behavioral responses to rewarding stimuli, such as glucose (Rolls, 2007). This same region of the brain has also been implicated in the management of self-control and performance monitoring (MacDonald, Cohen, Stenger, & Carter, 2007).

The findings of the present study imply that endurance athletes should avoid sporting scenarios that require self-control prior to competition. These could include conveying media-friendly messages, rather than true feelings, during interactions with fans or the media, as well as trying to regulate emotions during disagreements with teammates. It is important to acknowledge, however, that the Stroop task employed to experimentally manipulate self-control in the present study is not sport specific, and is relatively artificial in nature (Englert, 2016). The application of sport specific manipulations in future self-control experiments will make findings more relevant to sport practitioners. A second sporting implication is the use of glucose prior to competition. If glucose does interfere with self-regulatory pacing strategies as we speculated, then the popular habit of athletes consuming sports drinks prior to performance should be viewed with some scepticism.

Limitations and Future Directions

Methodologically speaking, the experimenter read the instructions for each cognitive task from a pre-prepared text to reduce the variability in the delivery of the instructions (Dorris et al., 2012), and the experimenter was out of sight from the participant as they completed the time trial task. Nonetheless, future research should blind the experimenter from the purpose of the study. Moreover, this study represents the primary attempt to examine previous exertion of self-control and subsequent gross motor skill endurance performance in well-trained athletes. Therefore, future research should attempt to replicate the findings in other endurance tasks (e.g., running) with expert populations to enhance the generalizability of the findings.

Manipulation checks are extremely difficult to conduct in ego depletion research because individuals are usually unable to subjectively report on having consumed resources during self-regulation (Baumeister & Vohs, 2016). Typically, self-reported mental exertion is measured following congruent versus incongruent Stroop tasks and our omission of this step represents a limitation. Instead we relied on the fact that previous research has unequivocally observed greater reports of mental exertion in incongruent trials relative to congruent trials. This implies that an incongruent Stroop task requires more self-control, relative to a congruent Stroop task (Hagger et al., 2010), and has been successfully used to initiate self-control in hundreds of previous studies[1]. Participant's performance on the Stroop task was also not assessed; however, we can be reasonably confident that Stroop performance did not influence our findings due to the within-person design that was implemented in the study. Such designs control for individual differences in performance on the self-control tasks, and may help to improve the replicability of the depletion effect (Cunningham & Baumeister, 2016). Also, the order of conditions was counterbalanced, therefore, potential confounds relating to reduced motivation (e.g., boredom so Stroop performance decreases), increased motivation (wanting to improve so Stroop performance increases) or learning effects (Stroop performance increases) are untenable.

That said, the findings described in this study question the hypothesis that self-control is a glucose-based resource that can be consumed. When combined with other lines or criticism (e.g., Kurzban, 2016), this represents a significant challenge to the resource model of self-control and alternative explanations should be examined. The ‘shifting priorities’ perspective, for example, proposes that reduced self-control is explained by changes in motivation and attention (Inzlicht & Schmeichel, 2016). Self-control process may also be linked to changes in affective states (Schmeichel & Inzlicht, 2013) that need to be considered. Consideration of motivation, mood states, and attention can be viewed as important extensions to the present work. For instance, asking participants to report their perceived physical discomfort and desire to reduce effort throughout an endurance performance task would provide valuable insight into shifting goal priorities. This will explore mechanisms behind performance decrements following self-control exertion, and will provide an empirical test of the hypothesis that self-control failure is due to shifts in motivational orientation and attentional focus (Inzlicht & Schmeichel, 2016).

Further research should manipulate the length of the second task and examine the effects of previous self-control exertion on subsequent endurance performance. It could be that the effects of self-control exertion may become more pronounced over time in endurance tasks lasting considerably longer. Moreover, it is possible that spending longer on the initial self-control task could consume more resources, decrease motivation, or enhance aversive affect, and have an increased deleterious effect on subsequent performance. To explore this, further research should manipulate initial task duration in a sequential-task paradigm and examine its effect on performance during the second task (Hagger et al., 2010). Such knowledge may help to inform the designing and evaluation of future experiments exploring self-control exertion and subsequent performance, and may help to resolve the current ongoing debate concerning the size of the depletion effect (Lee, Chatzisarantis, & Hagger, 2016).

Conclusion

This study helps understand the relationship between previous self-control exertion and subsequent highly practiced endurance performance. Our findings imply that pacing may explain why self-control exertion interferes with endurance performance. Finally, the debate regarding the exertion of self-control must consider that any observed effects may be dependent on the timing of performance inspection.

Footnote

[1] In a similar unpublished study we utilized an identical self-control manipulation (incongruent and congruent Stroop task lasting four minutes in duration) and employed Borg's single-item CR-10 scale (Borg, 1998) as a manipulation check to assess participants' perceived effort on the Stroop task. A repeated measures ANOVA revealed that participants reported higher mental exertion following the incongruent Stroop task ($M = 4.28$, $SD = .37$) compared to the congruent Stroop task ($M = 1.66$, $SD = .70$), $F(1,10) = 13.60$, $p = .01$).

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Table 1

Final Performance Time and Heart Rate for each Experimental Condition

	Time (seconds)		Heart Rate (beats per minute)	
Experimental Condition	*M*	*SD*	*M*	*SD*
Self-control/Glucose	1691	198	172	13
Self-control/Placebo	1706	222	173	13
Non-self-control/Glucose	1717	217	171	16
Non-self-control/Placebo	1652	185	175	14

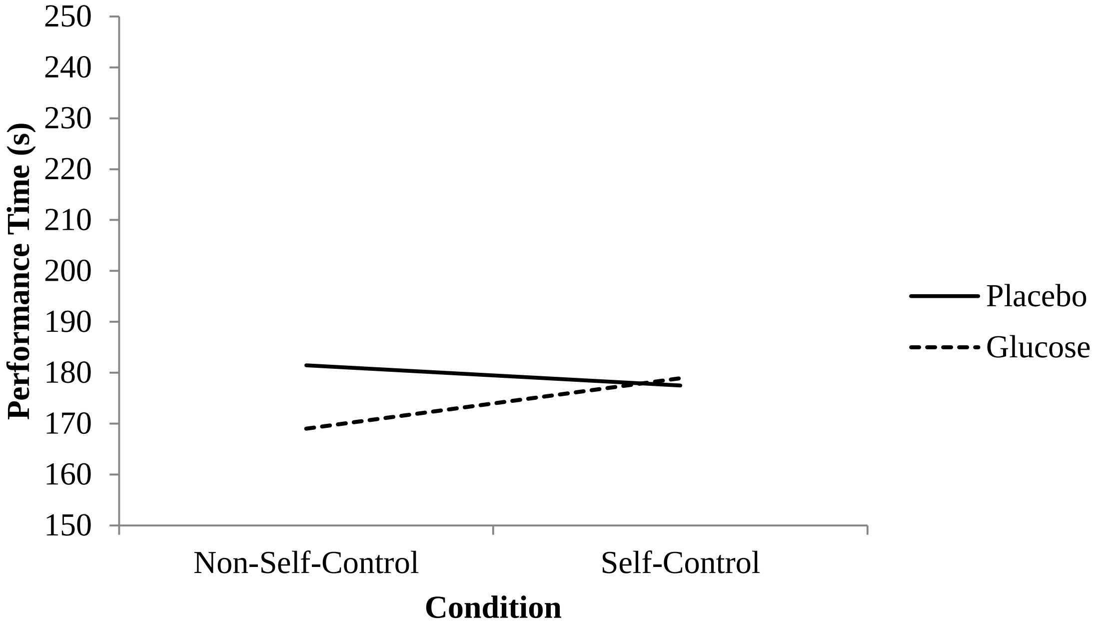
Table 2

Final Models Describing Changes in Study Variables during the Time Trial

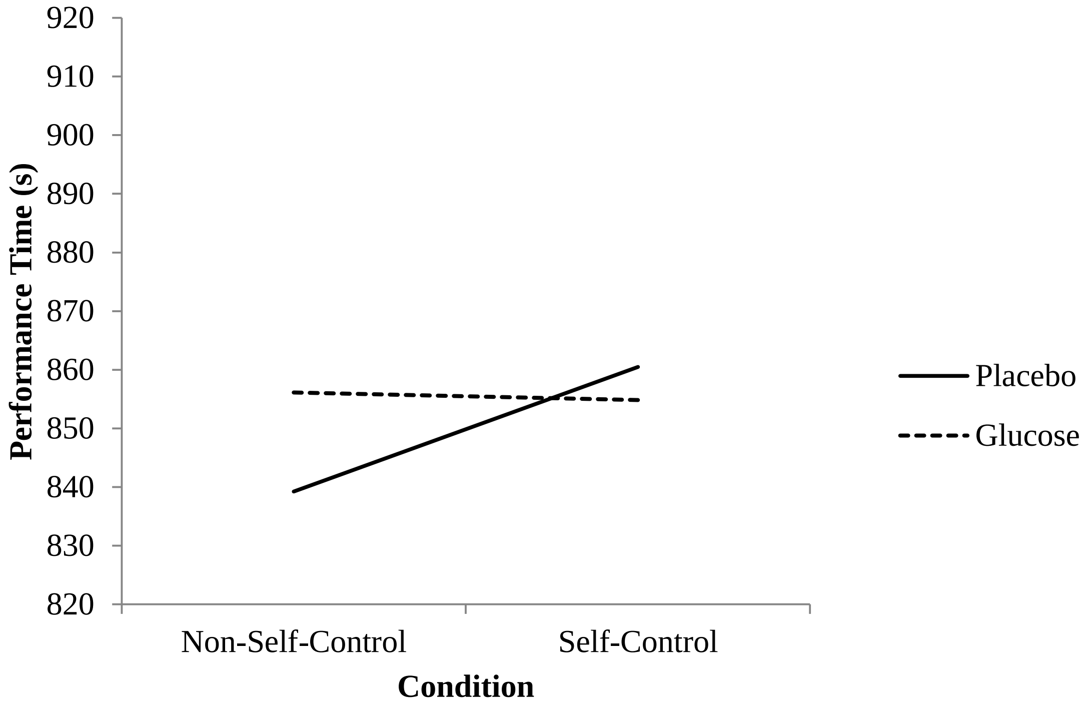
Predictor Variable	Model 1a	Model 1b	Model 2a	Model 2b
Fixed effects				
Intercept	1060.11(20.35)**	163.31(2.17)**	1661.42(36.60)**	173.71(4.02)**
Linear time	-	-	16.44(0.18)**	0.22(0.01)**
Self-control	-	-	52.80(55.67)	-2.83(6.12)
Glucose	-	-	53.60(52.96)	-6.31(8.82)
Glucose × self-control	-	-	-68.09(79.89)	5.89(8.78)
Self-control × time	-	-	0.63(0.27)**	-0.03(0.02)
Glucose × time	-	-	0.73(0.25)**	0.02(0.02)
Self-control × glucose × time	-	-	-0.91(0.38)**	0.02(0.03)
Daily Stress	-	-	-4.97(32.73)	0.83(3.63)
Random effects				
Level 1 residual variance	279582.75(15218.56)**	64.244(3.62)**	5414.97(305.10)**	27.07(1.53)**
Level 2 residual variance	0.00(0.00)	206.59(44.46)*	16400.21(3533.61)*	204.41(43.47)**

Note. A dash indicates that the term was not included in the models. *$p < .05$. **$p < .01$. ‘a’ models include performance as the dependent variable and ‘b’ models include heart rate.

a.


250
240
230
220
210
200
190
180
170
160
150
Performance Time (s)
Placebo
Glucose
Non-Self-Control
Self-Control
Condition

b.


920
910
900
890
880
870
860
850
840
830
820
Performance Time (s)
Placebo
Glucose
Non-Self-Control
Self-Control
Condition

c.

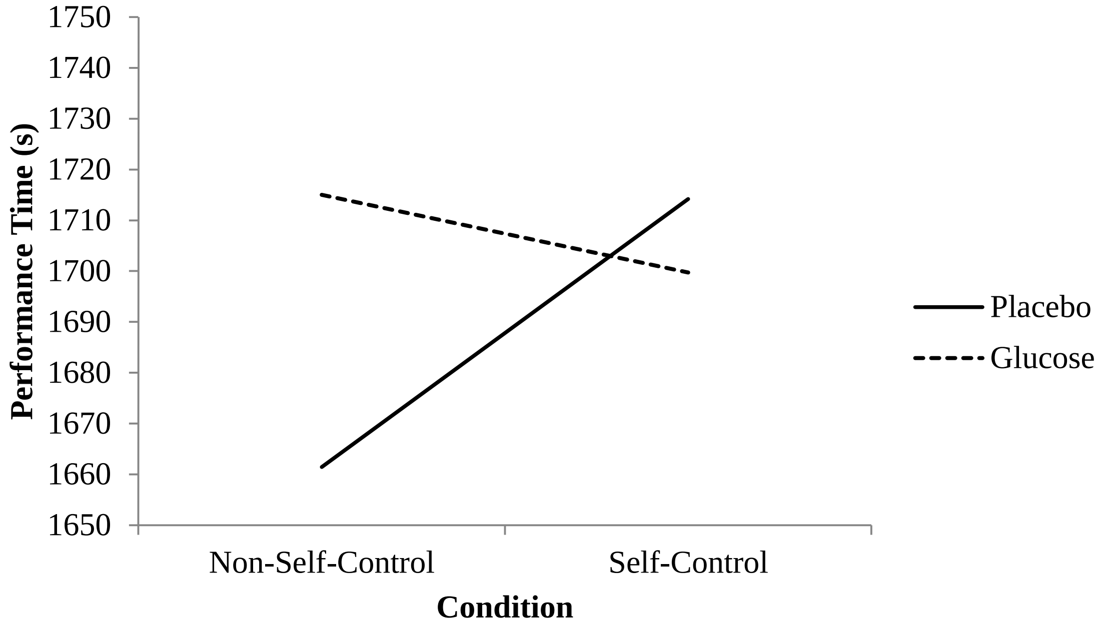


Figure 1. Three-way interaction effects for self-control and glucose conditions after 10 (graph a), 50 (b), and 100 (c) percent of the time trial had been completed.