Word count: 7.433

An investigation of the effects of self-reported self-control strength on shooting performance

Chris Englert[1,2,*], Anna Dziuba[2], Wanja Wolff[1,3], & Louis-solal Giboin[4]

[1]Institute of Educational Science, University of Bern, Fabrikstrasse 8, CH-3012 Bern, Switzerland. E-mail: christoph.englert@edu.unibe.ch

[2]Institute for Sport Sciences, Department of Sport Psychology, Goethe University Frankfurt, Ginnheimer Landstr. 39, D-60487 Frankfurt am Main, Germany. E-mail: englert@sport.uni-frankfurt.de; dziuba@sport.uni-frankfurt.de

[3]Department of Sport Sciences, Sport Psychology, University of Konstanz, Konstanz, Germany. E-Mail: wanja.wolff@uni-konstanz.de

[4]Sensorimotor Performance Lab, Human Performance Research Centre, Department of Sport Sciences, University of Konstanz, Germany. Email: louis-solal.giboin@uni-konstanz.de

*corresponding author

Declarations of interest: none.

Highlights

- Shooting performance deteriorates over time.
- Perceived state self-control decreases during shooting competition.
- Reduced state self-control precedes impaired shooting performance.
- Elite shooters display higher and more robust state self-control than sub-elites.

Abstract

During professional shooting tournaments, which typically last multiple hours, athletes must stay focused at all times in order to perform at their highest levels. Sustaining attention over extended periods of time relies on self-control. Crucially, perceived state self-control strength appears to wane as a function of task duration, which ultimately can impair shooting performance. In the present study, we tested the assumption that the level of self-reported self-control strength decreases over the course of a 1-hour shooting task measured twice during a regular training day and separated by a 2-hour break. Additionally, we assumed that shooting performance would be linked with fluctuations in self-control. A total of 21 shooters (14 elite and 7 sub-elite) took part in this study and were asked to perform a series of 10 shots at a standardized target, five times in the morning and five times in the afternoon (i.e., 100 shots total). The participants also reported their perceived state self-control strength at the baseline (prior to the start of the morning session as well as the afternoon session) and after a series of 10 shots each in the morning and afternoon (i.e., 12 measurements in total). In line with our hypotheses, we observed that perceived state self-control diminished with the number of shots performed, and that perceived state self-control could explain shooting performance. Additionally, these observations could explain the difference in shooting performance between elite and sub-elite athletes. The results suggest that the perception of self-control strength is highly important for optimal shooting performance. Practical implications are discussed.

Keywords: self-control, self-regulation, sports, shooting, Bayesian statistics

Introduction

Professional shooting tournaments can take up to three hours as a continuous competition, with athletes often being asked to compete in preliminary and main competitions, as well as the finals, in close chronological order (e.g., Chen & Mordus, 2018). To perform at their highest level, it is very important that the shooters remain focused during the entire competition day. Put more precisely, shooters must selectively regulate their attention for a prolonged duration (Boutcher, 2002; Laaksonen et al., 2018). However, athletes often find it difficult to maintain their attention over such a long period, which can ultimately lead to impaired performance (Abernethy, 2001; Abernethy et al., 2007). Thus, for sports that rely on precision (like shooting), efficient attention regulation is an important prerequisite for successful performance (Abernethy, 2001; Nieuwenhuys & Oudejans, 2011; Pelz et al., 2001). While performing the precision task, athletes must divert their attention from irrelevant internal (e.g., worrying thoughts) or irrelevant external (e.g., spectators) disturbing stimuli (i.e., *inhibition*) and instead shift their attention to the relevant targets on the shooting board (i.e., *shifting*; cf. Miyake et al., 2000). Previous studies adopting eye tracking technology to measure attention regulation have reliably shown that longer visual fixation durations on the relevant target areas are highly correlated with performance accuracy (e.g., Wilson et al., 2009). As Wilson and colleagues (2010) argue, “put simply, we move where we look” (p. 1356).

Theoretical work has identified the effective control of one’s attention as a key feature of self-control (Schmeichel & Baumeister, 2010; Wolff & Martarelli, 2020), and empirical work has shown that failure to apply self-control impairs performance in tasks that require attentional control (e.g., Englert et al., 2019). Importantly, self-control performance varies inter- and intra-individually, meaning that individuals do not only differ from each other in terms of their self-control performance (i.e., trait self-control; e.g., Tangney et al., 2004), but also that the self-control performances of the same individual might differ in seemingly similar situations (i.e., level of perceived state self-control strength; e.g., Schoendube, Bertrams, Sudeck, & Fuchs, 2017). Taken together, it is conceivable that differences in trait and state self-control affect performance outcomes in sports that rely on effective attention control (e.g., Englert et al., 2015). The focus of the current study will be on the variability of perceived state self-control strength and its effects on performance over time.

Researchers have long tried to understand the governing principles of self-control, putting special emphasis on why the ability (or willingness) to apply self-control seems to wane over time (e.g., Inzlicht & Schmeichel, 2012; Kurzban et al., 2013; Shenhav et al., 2013; Wolff & Martarelli, 2020). For example, the seminal strength model of self-control (Baumeister et al., 1998) suggests that individuals only possess a limited amount of self-control. This skill is needed to volitionally override immediate impulses or urges, which enables one to achieve higher-order goals (e.g., Baumeister et al., 2007). For instance, to achieve the goal of winning a shooting competition, an athlete has to resist any impulses that are likely to impair performance (e.g., reacting to distracting comments by rivals), which requires the application of self-control (e.g., Englert et al., 2015). However, individuals do not always control themselves, which, according to Baumeister and colleagues (1998), is especially likely if they had to control themselves in a preceding task. The model proposes that one’s state self-control strength can become temporarily exhausted after already engaging in a self-control-demanding task, leading to a state called *ego depletion*. Importantly, Baumeister et al. (1998) postulate that the effect of temporarily depleted self-control is not domain-specific, meaning that the various forms of self-control (e.g., emotion regulation, attention regulation, persistence) all depend on the same resource (for an overview, see Englert, 2016; 2017). It must be noted that this resource-based explanation of self-control has been questioned on an empirical as well as on a theoretical level (e.g., Beedie & Lane, 2012; Hagger et al., 2016; Wolff et al., 2018), and other theories that suggest different mechanisms by which prior application of self-control leads to impaired performance have been proposed (e.g., Inzlicht & Schmeichel, 2012; Kurzban et al., 2013; Wolff & Martarelli, 2020). However, different mechanistic explanations notwithstanding, most theories seem to agree that applying self-control is somehow costly (e.g., due to the sensation of effort it produces), and people are unwilling or unable to exert self-control for a prolonged duration (Wolff & Martarelli, 2020).

In line with this reasoning, research in sports has shown that prior engagement in a self-control-demanding task impairs subsequent sports performance (for two recent meta-analyses, see Brown et al., 2019; Giboin & Wolff, 2019). For example, athletes were less persistent and performed worse in an endurance task if they had previously been working on a cognitively demanding task that requires self-control (i.e., the *N*-back task; Dorris et al., 2012). In another study, athletes displayed a lower power output in an indoor cycling task after having performed a primary cognitively demanding task that requires self-control (i.e., the Stroop task; Stroop, 1935) compared to their performance under neutral conditions (Englert & Wolff, 2014; see also Wagstaff, 2014). Taken together, a substantial body of research has shown that perceived state self-control is important for sports performance (e.g., Englert, 2016; 2017).

Given that shooting performance relies greatly on attention control, and that attention control has been identified as the “single most important or influential form of self-control” (Schmeichel & Baumeister, 2010, p. 31), it is conceivable that differences in perceived state self-control strength are crucial for motor skill performance, such as shooting (for an overview, see Pageaux & Lepers, 2018). This supposition is supported by several studies; for instance, in a study by Englert and colleagues (Englert et al., 2015), individuals were less adept at selectively shifting their visual attention away from situationally irrelevant target areas to the task-relevant stimuli if they were previously required to control themselves in a foregoing task (see also Garrison et al., 2019). In the same vein, dart performance as well as basketball free-throw performance was worse if individuals had to work on a self-control task before (Englert & Bertrams, 2012; see also McEwan, Ginis, & Bray, 2013). When transferring these findings to a shooting task, which, as previously mentioned, is highly dependent on efficient attention regulation (e.g., Boutcher, 2002; Laaksonen et al., 2018), performance should suffer if an individual previously had to work on a self-control-demanding task. In support of this assumption, a study by Head and colleagues (2017) revealed that trained army soldiers performed worse in a shooting task if they had been working on a cognitively demanding task that requires self-control before. Given that attention regulation relies on self-control (Schmeichel & Baumeister, 2010), it can also be concluded that sustaining attention over a long period should affect perceived state self-control strength, which, in turn, should be associated with reduced performance (Thomson et al., 2015). As shooting tournaments often last multiple hours, during which athletes must remain focused and attentive (e.g., Chen & Mordus, 2018), perceived state self-control strength should decrease over the course of the tournament. However, research that tests this assumption in the field of elite performance or, more specifically, in regard to sports performance, is lacking.

The present study

Here, we investigate the temporal dynamics of perceived state self-control strength and shooting performance in a sample of elite- and sub-elite-level shooters. We monitor perceived state self-control strength because research has shown that, irrespective of whether self-control can actually be *depleted*, changes in *perceived* state self-control strength are crucial for performance in self-control-demanding tasks (Job et al., 2010). Specifically, we test three main research questions. First, shooters must selectively regulate attention for a prolonged duration during shooting competitions. This should lead to a reduction in shooters' perceived state self-control strength as a function of time and, further downstream, to reduced performance. Thus, we test the hypotheses that perceived state self-control strength and objectively measured shooting performance deteriorate over the course of a 1-hour shooting task; the task was performed at two time points separated by a 2-hour break during a regular training day (T1, in the morning; T2, in the afternoon). Second, self-control is expected to be the mental capacity that allows people to voluntarily control their attention, and effective attention control is a prerequisite for good shooting. Thus, we test the hypothesis that changes in perceived state self-control strength predict changes in objectively measured performance. Importantly, this implies that, for perceived state self-control strength to predict changes in performance, changes in perceived state self-control strength *prior* to a shooting sequence should be better predictors of performance than are state self-control measures taken *after* the shooting sequence. Third, emerging research indicates that superior athletes are better at controlling their impulses (e.g., Martin et al., 2016). It is therefore plausible that the temporal dynamics of perceived state self-control strength and shooting performance, as well the self-control × performance interaction, in elite athletes differ from those of sub-elite athletes. As we had no specific a priori hypothesis regarding the nature of these differences, this hypothesis was tested exploratively.

Method

Participants

The sample consisted of 21 shooters (7 women, 14 men; M_{age} = 17.33, SD_{age} = 4.32; shooting experience: *M* = 5.46 years, *SD* = 3.77; training per week: *M* = 221.90 min, *SD* = 115.26; all participants were Caucasian and native German speakers) from two training groups (14 elite athletes from an Olympic training facility in Germany, and 7 sub-elite athletes from a shooting club in Germany) who participated voluntarily. Five additional participants' data had to be excluded from the analyses because they completed only one shooting round. All participants gave written informed consent based on APA's ethics code before taking part in the research.

Design, Procedure, and Measures

The study was conducted during regular training sessions at the respective training facilities under standardized experimental conditions. All instructions and questionnaires were delivered as paper and pencil versions in German and all measures taken during this study are reported in the current report. First, participants provided written informed consent and reported demographic information (i.e., age, gender, shooting experience, training per week in hours).

Next, they were informed that they would be asked to complete two shooting rounds of 50 shots each on the same day, from a distance of 10 meters on a regular shooting board (International Shooting Sport Federation, 2020). To match the data from the two shooting rounds, each participant was assigned a unique anonymous code. In line with the official shooting regulations of the International Shooting Sport Federation (ISSF), there were 10 concentric rings depicted on the face of the target, with points assigned to each circle, ranging from 10 for the center of the target to 0 when the board was not hit at all (International Shooting Sport Federation, 2020). The participants were asked to always aim for the highest score (i.e., the center of the board). There was a break of 2 hours between the two shooting rounds. The maximum time per shooting round was chosen based on the regular competition time, and therefore was about one hour. During both shooting rounds, shooting performance was recorded via electronic scoring targets using LED infrared light barriers (for this procedure, see International Shooting Sport Federation, 2020).

Before starting with the shooting block (in the morning and the afternoon) and after each block of 10 shots, perceived state self-control strength was measured using the German 5-Item Brief State Self-Control Capacity Scale (SMS-5; Lindner et al., 2019). The SMS-5 is an adoption of the State Self-Control Capacity Scale (SSCS; Ciarocco, Twenge, Muraven, & Tice, 2007) which has been frequently applied in sport psychological research (e.g., Graham, Martin Ginis, & Bray, 2017). SMS-5 scores predict performance in self-control demanding tasks (criterion validity), while being unrelated to performance scores in tasks that had been performed on other days, thereby attesting to the divergent validity of the scale and its ability to capture state-like fluctuations in perceived self-control strength (Lindner et al., 2019). In addition, Lindner et al. (2019) showed that the SMS-5 performs similar to the SSCS in predicting external criteria, indicating that it is an efficient, reliable and valid measure for capturing perceived state self-control strength. Each of the five items ("I feel drained"; "I feel calm and rational"*; "I feel lazy"; "I feel sharp and focused"*; "I feel like my willpower is gone"; *inverted item) was answered on a scale from 1 ("not true") to 7 ("very true") in regard to the individual's current state ("Please reply spontaneously to the following statements about how you feel at the moment"). In total, the participants completed these questions 12 times (the internal consistencies for each time of measurement are depicted in Table 1). For each application of the SMS-5, overall scores were computed by averaging each participant's answers, with higher scores always indicative of higher levels of perceived state self-control strength.

Finally, after having performed the final shooting block, all participants were debriefed and thanked for their participation.

Data Analytic Strategy

Since self-control was measured at the baseline (i.e. before any shooting attempt in both sessions), and just after each shooting block, we could express variation in self-control as a percentage of baseline self-control (SCbase). This way, individual baseline differences in self-control could be discounted, leading to more accurate estimates of changes in self-control that occurred over the course of the shooting task. Additionally, we were interested in the relationship between shooting performance and self-control when self-control was measured before (SCpre) and after (SCpost) the shooting block. We used SCpre to test if the self-reported self-control level before a shooting block could predict subsequent shooting performance. We used SCpost to test whether prior shooting performance could predict the level of subsequent self-control.

All statistical tests were performed with Bayesian linear mixed models, using the R package *brms* (Bürkner, 2017; 2018). For all models, we used the default *brms* priors since they are weakly informative, which reduces the influence of priors on the statistical results (see the *brms* package manual for more details). We used four Markov Chain Monte Carlo procedures with 4,000 iterations per chain (2,000 for warm-up) and checked that all models converged correctly. To obtain more insights from the models, we used the built-in function *hypothesis()* from the package *brms*, which allows the calculation of complex contrasts (see the *brms* manual). QQplots showed that performance (Performance), self-control expressed as a percentage of the baseline (SCbase), and self-control measured before or after shooting (SCpre and SCpost, respectively) followed approximatively normal quantiles. To obtain QQplots, we used the *qqplotr* R package with confidence intervals based on an inversion of the Kolmogorov-Smirnov test (Almeida et al., 2018).

In our first research question, we were interested in the temporal dynamics of SCbase and Performance across blocks of shooting (as a numeric factor). Simply put, we tested whether self-control and performance changed over the course of a shooting session. For this, we pooled the SCbase or Performance measurements from both sessions and used a model with maximized errors to limit type I issues (Barr et al., 2013). Specifically, we used a model with random intercepts by subjects and random slopes by subjects for the fixed effect of shooting blocks (DV ~ Blocks + (Blocks | Subject), formula which can be described as: dependent variable is explained by the fixed effect "Blocks", to which we add a random effect for each subject, sampled from a Gaussian distribution with mean zero and standard deviation sigma to be determined). Therefore, with this model we could check whether SCbase or Performance was decreasing across blocks, while taking into account differences of SCbase or Performance variations between subjects.

In our second research question, we examined the overall relationship between Performance and SCbase. For this, we clustered all shooting performance measurements per subject and used a model with SCbase as a fixed numeric factor with random intercepts and slopes per subject (Performance ~ SCbase + (SCbase | Subject)). We used this model to test our hypothesis that changes in self-control covary with changes in performance.

Finally, we constructed a model to explain Performance according to blocks of shooting and SCbase and their interaction (all fixed effects; Performance ~ SCbase × Blocks + (SCbase × Blocks | Subject)). Finally, we investigated whether the athletic level (elite vs. sub-elite) affects the relationship between self-control, shooting, and shooting performance. For this series of analyses, we used SCpre instead of SCbase, because we expected both groups to have different levels of self-control at the baseline, which could explain differences in shooting performance in the first block of shooting. First, we verified that there was a difference in shooting performance between groups. For this, we clustered all the Performance measurements per subject and used a simple group comparison model (DV ~ Group + (1 | Subject)). We then constructed a model to test whether self-control (with SCpre) or shooting performance was modulated differently across shooting blocks per group, i.e. if there was an interaction between groups and shooting blocks (DV ~ Blocks × Group + (Blocks | Subject)). Finally, to investigate whether the relationship between SCpre and Performance was different between groups, we used the following model: Performance ~ SCpre × Group + (SCpre | Subject). Model results are given under the form mean posterior estimate [lower boundary of the 95% credible interval, upper boundary of the 95% credible interval].

Additionally, we have calculated effect sizes when relevant, using the Cohen's *dz* for within subject effect sizes and Cohen's *ds* for between subjects effect sizes (see also Lakens, 2013).

Post-hoc power analysis

To assess the statistical significance of our analyses, we performed a retrospective Bayesian power analysis on the main result of the paper, i.e. observing a reduction of SCbaseline across the shooting blocks. For this power analysis, we used the same model than in the paper (linear mixed model with maximized error structure), and simulated data following normal distribution and with a credible decrease of 3% of SCbaseline per block of shooting and with a standard deviation of 20. This analysis showed that with the number of subject used, we had a power of 0.87, which is higher than the usual power threshold of 0.8. Please note that using linear mixed models provides higher power than an ANOVA when multiple measurements per condition and per subject are collected (as presently).

This power analysis method requires high computing power (since tests have to be repeated an extensive number of time), which limits our capacity to perform power analysis on all tests. This is why we have not performed power analysis for models testing the interactions between elite and sub-elite athletes. The readers are invited to consider the results from these tests with caution and potentially influenced by the small sample size used.

– Table 1 about here –

Results

Supporting our first research question, SCbase decreased across shooting blocks (beta coefficient, which represents the slope of SCbase across blocks = -2.75% [-4.708, -0.801] per shooting block), with a total loss close to 14% in the last block (see Figure 1A) and an effect size dz = 0.22 between the first and last block. However, the decrease of Performance across blocks was not as clear (beta coefficient = -0.03 [-0.07, 0.01], see Figure 1B).

Supporting our second research question and attesting to the relevance of self-control in the shooting context, changes in Performance could be explained by changes in SCbase (beta coefficient = 0.007 [0.002, 0.013] points of shooting score per 1% increase in self-control; see Figure 1C). Interestingly, this overall relationship between performance and self-control could also be observed when self-control was measured before shooting (beta coefficient for the effect of SCpre on Performance = 0.164 [0.067, 0.264] points of shooting score per unit of self-control), but not when self-control was measured after shooting (beta coefficient for the effect of SCpost on Performance = 0.028 [-0.052, 0.108] points of shooting score per unit of self-control). Finally, in a model controlling for the effect of blocks of shooting and SCbase and their interaction, we could see that Performance was explained by SCbase (0.012 [0.005, 0.020] points of shooting score per unit of self-control) but not by blocks of shooting (0.116 [-0.046, 0.278] points of shooting performance per block). Surprisingly, it is possible that a small interaction effect between SCbase and blocks could reduce the effect of SCbase on Performance with the number of shooting blocks performed (-0.001 [-0.003, 0.000]). It must also be noted that, at the group level (i.e., at the subject level), the model indicated a strong negative correlation (-0.851 [-0.981, -0.384]) between the subject's intercept and slope across SCbase, suggesting that subjects who are the most impaired by low self-control benefit the most from high self-control.

- Figure 1 about here -

In regard to our third research question, sub-elite-level athletes' shooting was clearly at a lower performance level than that of elite-level athletes (-0.810 [-1.532, -0.090] points of shooting performance, effect size *ds* = 0.96). Interestingly, as displayed in Figure 2A, this difference of performance seems to stem from a slightly better overall performance by elite athletes, but also from a reduction of performance across shooting blocks in sub-elite-level athletes. The model indicated that there was no clear difference in the slopes of shooting blocks between groups (beta of the difference between elite-level and sub-elite-level athletes = -0.057 [-0.142, 0.027]). However, this effect, along with the effect of shooting blocks, was enough to demonstrate that there was a growing difference in performance across shooting blocks: the difference of shooting performance between elite-level and sub-elite-level athletes at shooting block 1 = 0.70 [0.00, 1.38], and the difference at block 5 = 0.93 [0.11, 1.74] with an effect size *ds* = 0.99 at block 5. Interestingly, a similar pattern was observed between groups with regard to SCpre (Figure 2B). The model showed a clear difference between slopes across shooting blocks (beta of the difference between elite-level and sub-elite-level athletes = -0.311 [-0.525, -0.093]), and thus a growing difference across blocks between groups: no difference in SCpre between elite-level and sub-elite-level athletes at shooting block 1 = 0.46 [-0.31, 1.24], and a large difference at block 5 = 1.71 [0.86, 2.55] with an effect size *ds* = 2.21 at block 5. Again, interestingly, a strong negative correlation could be observed at the subject level between the intercept and the slope of SCpre across shooting blocks (-0.63 [-0.846, -0.274]). Finally, as displayed in Figure 2C, the model taking into account the fixed effects of Group, SCpre, and their interaction showed that, at a low level of SCpre, there was no clear difference in the effect of SCpre on Performance between groups (when SCpre = 2, difference of Performance between elite-level and sub-elite-level = 0.52 [-0.61, 1.66]), while at a high level of SCpre, elite-level athletes performed better than did sub-elite-level athletes (when SCpre = 7, difference of Performance between elite-level and sub-elite-level = 0.77 [0.14, 1.39]). A strong negative correlation was also observed at the subject level between the intercept and the slope of Performance across SCpre (-0.911 [-0.988, -0.716]).

- Figure 2 about here -

Discussion

We found that self-control at baseline (SCbase) but not shooting performance, decreases across shooting blocks, and that SCbase and self-control measured before shooting (SCpre), but not self-control measured after shooting (SCpost), explain shooting performance. Further, we observed that elite shooters had a higher shooting performance and SCpre, and a lower decrease of shooting performance and SCpre, across blocks than did sub-elite shooters. Furthermore, among elite shooters, SCpre exerted a stronger effect on shooting performance at high levels of self-control compared to among sub-elite shooters.

For optimal shooting performance, shooters must stay focused during the full competition, which typically lasts multiple hours (e.g., Chen & Mordus, 2018). Irrelevant stimuli must be ignored while attention is directed to the task at hand (e.g., Boutcher, 2002; Laaksonen et al., 2018). However, continuous self-control exertion does not always work. Sustaining attention over extended periods is mentally draining and requires self-control (e.g., Schmeichel & Baumeister, 2010). Previous research has reliably shown that self-control performance is less efficient if an individual had previously been working on self-control-demanding tasks (e.g., Brown et al., 2019; Giboin & Wolff, 2019). In the current study, the results supported our expectation that individuals' perceived state self-control strength would decrease over the course of a long-lasting training session, and that perceived state self-control strength would predict shooting performance. Individuals who reported lower levels of self-control strength performed worse. Further, as expected, elite athletes displayed better and more robust (i.e., less performance deterioration over time) shooting performance than did sub-elite athletes. Attesting to the importance of self-control, these differences in the temporal dynamics of shooting performance were mirrored by similar differences in perceived state self-control strength. However, it must be acknowledged by the readers that differences observed between elite and sub-elite athletes are possibly influenced by our low sample size, and cautions must be taken when interpreting these results.

Phenomenologically, the results are in line with the strength model of self-control, which postulates that there is only a limited amount of available self-control strength that can become temporarily depleted after having previously engaged in self-control activities (e.g., Baumeister et al., 1998). While the present findings follow the propositions of the strength model, our work is not designed to test the mechanistic underpinnings of the strength model, and our findings are also in line with more recent theorizing about self-control. This is important because the merit of the strength model has been questioned; recent studies have failed to provide empirical support for ego depletion effects (e.g., Hagger et al., 2016) and research indicating that the depletable resource might in fact be glucose has not been robustly replicated (Lange & Eggert, 2014). In addition, others have questioned the mechanistic foundation of the strength model altogether (Kurzban et al., 2013). For example, recent work suggests that, rather than reflecting a biological limitation (i.e., a limited resource that gets depleted when people apply self-control), self-control appears to wane because of functional processing constraints (Shenhav et al., 2017) or because of the opportunity costs its application produces (Kurzban et al., 2013). According to these alternative explanations, the aversive sensations (e.g., effort, fatigue) that accompany the prolonged application of self-control (Wolff et al., 2019) signal the rising costs of applying control (Wolff & Martarelli, 2020). Thus, current theorizing proposes a mechanistic link between the phenomenology that tends to accompany the prolonged application of self-control (i.e., effort, fatigue) and the subsequent motivation to further invest self-control (Wolff & Martarelli, 2020). This claim is based on recent theoretical and empirical work, showing that prolonged application of self-control reduces the motivation to further exert self-control (Inzlicht & Schmeichel, 2012; Lin, Saunders, Friese, Evans, & Inzlicht, 2020; Wolff & Martarelli, 2020) and this is accompanied by sensations of fatigue (Wolff, et al., 2019) and changes in neural processing of task demands (Boksem, Meijman, & Lorist, 2005). Thus, exerting self-control to regulate attention for a prolonged duration is expected to increase control costs, thereby skewing the cost–reward analysis away from control application (see also, André, Audiffren, & Baumeister, 2019). This is in line with our observation of reduced perceived energy levels (i.e., diminished perceived state self-control strength) as a function of time and the detrimental effect this reduction has on shooting performance. Future research should continue to dig deeper into the potential psychological (e.g., boredom, motivation, self-efficacy), phenomenological (e.g., fatigue, effort) as well as neuronal mechanisms leading to lapses in self-control performance in various domains (e.g., Pageaux & Lepers, 2018). For example, recent works suggests that tasks that are designed to pose varying levels of self-control demands can induce the sensation of boredom (Wolff & Martarelli, 2020), and the effects of boredom on fatigue (Milyavskaya, Inzlicht, Johnson, & Larson, 2019) , performance (Bieleke, Barton, & Wolff, 2020) and neuronal processing (Milyavskaya et al., 2019) have been shown to mirror or even outweigh those of self-control exertion. Thus, future research should focus on unraveling the joint, as well as the independent contribution of perceived state self-control, fatigue and boredom on tasks that require prolonged self-control.

We would also like to mention that even though we argue that efficient attention regulation is impaired after having previously engaged in self-control, we did not explicitly measure attention regulation, as it was not our primary variable of interest. Nonetheless, future studies should not only investigate changes in self-reported self-control and its effects on performance over time, but also how these changes are related to changes in attention regulation, for instance by applying eye-tracking technology (e.g., Wilson et al., 2009).

Interestingly, in our study elite athletes were less prone to perceived state self-control strength decreases over time than were sub-elite athletes. How can these effects of expertise on perceived state self-control strength be explained? The most logical interpretation would be that elite-level shooters are used to sustaining their attention during tournaments for multiple hours (Di Fronso et al., 2016). Therefore, it should be less cognitively demanding for them to stay focused, and they need to invest less self-control strength, than sub-elite-level shooters. This interpretation is also in line with computational work on the functional processing architecture of the human information processing system; it has been suggested that, while the human brain generally favors multiplexing (i.e., use of shared processing pathways for different tasks) over multitasking (i.e., task-specific processing pathways), repeated exposure to certain processing demands (e.g., regulating attention in the service of shooting performance) automatizes information processing, leading to the development of task-specific processing pathways (Feng et al., 2014). Additionally, training can enhance attentional control (Bavelier & Green, 2019), partly due to the increased capability of suppressing cortical processing of distracting information (Mishra et al., 2011), which could theoretically reduce the use of self-control strength in well-trained shooters. An alternative explanation could be that elite shooters differ from sub-elite shooters in terms of their implicit theories about self-control. Job and colleagues (2010) argue that the negative carry-over effects of a primary self-control act on subsequent self-control performance can be primarily observed in individuals who actually believe that self-control cannot be exerted infinitely. On the contrary, individuals who do not believe in ego depletion or limited self-control resources are less affected by previous self-control acts. Future studies might consider the effects of implicit theories on self-reported self-control strength and shooting performance over time.

Finally, we would like to discuss the matter of causality. Our data are strictly correlational, which is why future studies might adopt experimental designs to replicate and extend our findings. For instance, research on cognitive fatigue and ego depletion would argue that these states can be induced by asking individuals to work on cognitively demanding tasks that require self-control for a prolonged period. Research on mental fatigue suggests that the cognitively demanding task should last at least 30 minutes to reliably induce mental fatigue (van

Cutsem et al., 2017), while states of ego depletion can supposedly be induced by much shorter durations (e.g., Baumeister et al., 1998). Even though these experimental designs seem enticing, it should be noted that recent research adopting the two-task paradigm has delivered mixed results (e.g., Wolff et al., 2019). In addition, a recent meta-analysis did not find evidence of a correlation between the length of prior mental exertion and the effect size of ego depletion or mental fatigue (Giboin & Wolff, 2019; see also Brown et al., 2019).

Concluding remarks

The present study yields insights into how sustained attention over extended periods can affect the level of self-reported self-control strength and how these subjective interpretations can, in turn, affect shooting performance. As the subjective interpretations of the level of self-control strength rather than depleted metaphorical resources seem to be key to subsequent performance, future studies should aim to develop techniques to change implicit theories about self-control from a limited theory to an infinite theory (e.g., Job et al., 2010).

Acknowledgments

We would like to thank Robin Steinkühler, Helena Weiler, and Lukas Reichert for their help in data collection.

Declaration of interest statement

No potential conflict of interest was reported by the authors.

Data availability statement

The data file is available at Figshare with this private link: https://figshare.com/s/371128d74fc76838c544 (data will be publicly available after acceptance of the article).

Funding details

This work was supported by the German Federal Institute of Sport Science under grant number 072004/19-20.

References

Abernethy, B. (2001). Attention. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of Sport Psychology* (Vol. 2, pp. 55–85). Wiley.

Abernethy, B., Maxwell, J. P., Masters, R. S. W., Van der Kamp, J., & Jackson, R. C. (2007). Attentional processes in skill learning and expert performance. In G. Tenenbaum & R. C. Ecklund (Eds.), *Handbook of Sport Psychology* (Vol. 3, pp. 245–263). Wiley.

Almeida, A., Loy, A., & Hofmann, H. (2018). ggplot2 Compatible Quantile-Quantile Plots in R. *The R Journal, 10*(2), 248–261. doi:10.32614/RJ-2018-051

André, N., Audiffren, M., & Baumeister, R. F. (2019). An integrative model of effortful control. *Frontiers in Systems Neuroscience, 13*, 79. doi:10.3389/fnsys.2019.00079

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255–278. doi:10.1016/j.jml.2012.11.001

Bavelier, D., & Green, C. S. (2019). Enhancing attentional control: Lessons from action video games. *Neuron, 104*, 147–163. doi:10.1016/j.neuron.2019.09.031

Beedie, C. J., & Lane, A. M. (2012). The role of glucose in self-control: Another look at the evidence and an alternative conceptualization. *Personality and Social Psychology Review, 16*, 143–153. doi:10.1177/1088868311419817

Bieleke, M., Barton, L., & Wolff, W. (2020). *Trajectories of boredom in self-control demanding tasks*. https://doi.org/10.31234/osf.io/ekqrv

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2005). Effects of mental fatigue on attention: an ERP study. *Cognitive Brain Research*, *25*(1), 107-116. doi:10.1016/j.cogbrainres.2005.04.011

Boutcher, S. H. (2002). Attentional processes and sport performance. In T. S. Horn (Ed.), *Advances in Sport Psychology* (Vol. 2, pp. 441–457). Human Kinetics.

Brown, D. M., Graham, J. D., Innes, K. I., Harris, S., Flemington, A., & Bray, S. R. (2019). Effects of prior cognitive exertion on physical performance: A systematic review and meta-analysis. *Sports Medicine, 50*, 497–529. doi:10.1007/s40279-019-01204-8

Bürkner, P-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software, 80*, 1–28. doi:10.18637/jss.v080.i01

Bürkner, P-C. (2018). Advanced Bayesian multilevel modeling with the R package brms. *The R Journal, 10*, 395–411. doi:10.32614/RJ-2018-017

Chen, Y. T., & Mordus, D. (2018). Shooting sports. In A. J. De Luigi (Ed.), *Adaptive Sports Medicine* (pp. 313–322). Springer. doi:10.1007/978-3-319-56568-2_25

Ciarocco, N. J., Twenge, J. M., Muraven, M., & Tice, D. M. (2007). *Measuring state self-control: Reliability, validity, and correlations with physical and psychological stress.* Unpublished manuscript, Monmouth University, NJ, USA.

Di Fronso, S., Robazza, C., Edson Filho, L. B., Comani, S., & Bertollo, M. (2016). Neural markers of performance states in an Olympic athlete: An EEG case study in air-pistol shooting. *Journal of Sports Science and Medicine, 15*, 214–222. PMCID: PMC4879433

Dorris, D. C., Power, D. A., & Kenefick, E. (2012). Investigating the effects of ego depletion on physical exercise routines of athletes. *Psychology of Sport and Exercise, 13*, 118–125. doi:10.1016/j.psychsport.2011.10.004

Englert, C. (2016). The strength model of self-control in sport and exercise psychology. *Frontiers in Psychology, 7*, 314. doi:10.3389/fpsyg.2016.00314

Englert, C. (2017). Ego depletion in sports: highlighting the importance of self-control strength for high-level sport performance. *Current Opinion in Psychology, 16*, 1–5. doi:10.1016/j.copsyc.2017.02.028

Englert, C., & Bertrams, A. (2012). Anxiety, ego depletion, and sports performance. *Journal of Sport and Exercise Psychology, 34*, 580–599. doi:10.1123/jsep.34.5.580

Englert, C., Koroma, D., Bertrams, A., & Martarelli, C. S. (2019). Testing the validity of the attention control video: An eye-tracking approach of the ego depletion effect. *PLOS ONE*, *14*(1). doi: 10.1371/journal.pone.0211181

Englert, C., & Wolff, W. (2015). Ego depletion and persistent performance in a cycling task. *International Journal of Sport Psychology, 46*, 137–151.

Englert, C., Zwemmer, K., Bertrams, A., & Oudejans, R. R. D. (2015). Ego depletion and attention regulation under pressure: Is a temporary loss of self-control strength indeed related to impaired attention regulation? *Journal of Sport and Exercise Psychology, 37*, 127–137. doi:10.1123/jsep.2014-0219

Feng, S. F., Schwemmer, M., Gershman, S. J., & Cohen, J. D. (2014). Multitasking versus multiplexing: Toward a normative account of limitations in the simultaneous execution of control-demanding behaviors. *Cognitive, Affective, and Behavioral Neuroscience, 14*, 129–146. doi:10.3758/s13415-013-0236-9

Garrison, K. E., Finley, A. J., & Schmeichel, B. J. (2019). Ego depletion reduces attention control: Evidence from two high-powered preregistered experiments. *Personality and Social Psychology Bulletin, 45*, 728–739. doi: 10.1177/0146167218796473

Giboin, L. S., & Wolff, W. (2019). The effect of ego depletion or mental fatigue on subsequent physical endurance performance: A meta-analysis. *Performance Enhancement and Health*, *7*, 100150. doi:10.1016/j.peh.2019.100150

Graham, J. D., Martin Ginis, K. A., & Bray, S. R. (2017). Exertion of self-control increases fatigue, reduces task self-efficacy, and impairs performance of resistance exercise. *Sport, Exercise, and Performance Psychology, 6*, 70–88. doi:10.1037/spy0000074

Hagger, M. S., Chatzisarantis, N. L. D., Alberts, H., Anggono, C. O., Batailler, C., Birt, A. R., Brand, R., Brandt, M. J., Brewer, G., Bryneel, S., Calvillo, D. P., Campbell, W. K., Cannon, P. R., Carlucci, M., Carruth, N. P., Cheung, T., Crowell, A., De Ridder, D. T. D., Dewitte, S., . . . Zwienenberg, M. (2016). A multilab preregistered replication of the ego-depletion effect. *Perspectives on Psychological Science, 11*, 546–573. doi: 10.1177/1745691616652873

Head, J., Tenan, M. S., Tweedell, A. J., LaFiandra, M. E., Morelli, F., Wilson, K. M., ... & Helton, W. S. (2017). Prior mental fatigue impairs marksmanship decision performance. *Frontiers in Physiology*, 8, 680. doi:10.3389/fphys.2017.00680

International Shooting Sport Federation. (2020). *General technical rules*. Retrieved from ISSF website: https://www.issf-sports.org/getfile.aspx?mod=docf&pane=1&inst=458&file=1.%20ISSF%20General%20Technical%20Rules.pdf

Inzlicht, M., & Schmeichel, B. J. (2012). What is ego depletion? Toward a mechanistic revision of the resource model of self-control. *Perspectives on Psychological Science, 7*, 450–463. doi: 10.1177/1745691612454134

Job, V., Dweck, C. S., & Walton, G. M. (2010). Ego depletion—Is it all in your head? Implicit theories about willpower affect self-regulation. *Psychological Science, 21*, 1686–1693. doi:10.1177/0956797610384745

Kurzban, R., Duckworth, A., Kable, J. W., & Myers, J. (2013). An opportunity cost model of subjective effort and task performance. *Behavioral and Brain Sciences, 36*, 661–679. doi:10.1017/S0140525X12003196

Laaksonen, M. S., Finkenzeller, T., Holmberg, H. C., & Sattlecker, G. (2018). The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: A review. *Journal of Sport and Health Science, 7*, 394–404. doi:10.1016/j.jshs.2018.09.003

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 863. doi:10.3389/fpsyg.2013.00863

Lange, F., & Eggert, F. (2014). Sweet delusion. Glucose drinks fail to counteract ego depletion. *Appetite*, *75*, 54-63.

Lin, H., Saunders, B., Friese, M., Evans, N. J., & Inzlicht, M. (2020). Strong effort manipulations reduce response caution: A preregistered reinvention of the ego-depletion paradigm. *Psychological science*, *31*(5), 531-547. doi:10.1177/0956797620904990

Lindner, C., Lindner, M. A., & Retelsdorf, J. (2019). Die 5-Item-Skala zur Messung der momentan verfügbaren Selbstkontrollkapazität (SMS-5) im Lern-und Leistungskontext: Eine Validierungsstudie [Measuring self-control depletion in achievement situations: A validation of the 5-item brief state self-control capacity scale]. *Diagnostica, 65*, 228–242. doi:10.1026/0012-1924/a000230

Martin, K., Staiano, W., Menaspà, P., Hennessey, T., Marcora, S., Keegan, R., Thompson, K. G., Martin, D., Halson, S., & Rattray, B. (2016). Superior inhibitory control and resistance to mental fatigue in professional road cyclists. *PLOS ONE, 11*(7). doi:10.1371/journal.pone.0159907

McEwan, D., Ginis, K. A. M., & Bray, S. R. (2013). The effects of depleted self-control strength on skill-based task performance. *Journal of Sport and Exercise Psychology, 35*, 239-249. doi:10.1123/jsep.35.3.239

Milyavskaya, M., Inzlicht, M., Johnson, T., & Larson, M. J. (2019). Reward sensitivity following boredom and cognitive effort: A high-powered neurophysiological investigation. *Neuropsychologia*, *123*, 159-168. doi:10.1016/j.neuropsychologia.2018.03.033

Mishra, J., Zinni, M., Bavelier, D., & Hillyard, S. A. (2011). Neural basis of superior performance of action videogame players in an attention-demanding task. *Journal of Neuroscience, 31*, 992–998. doi:10.1523/JNEUROSCI.4834-10.2011

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100. doi:10.1006/cogp.1999.0734

Nieuwenhuys, A., & Oudejans, R. R. (2011). Training with anxiety: Short-and long-term effects on police officers’ shooting behavior under pressure. *Cognitive Processing, 12*, 277–288. doi:10.1007/s10339-011-0396-x

Pageaux, B., & Lepers, R. (2018). The effects of mental fatigue on sport-related performance. In S. Marcora, & M. Sarkar (Eds.), *Progress in Brain Research* (Vol. 240, pp. 291-315). Elsevier. doi:10.1016/bs.pbr.2018.10.004

Pelz, J., Hayhoe, M., & Loeber, R. (2001). The coordination of eye, head, and hand movements in a natural task. *Experimental Brain Research, 139*, 266–277. doi:10.1007/s002210100745

Schmeichel, B. J., & Baumeister, R. F. (2010). Effortful attention control. In B. Bruya (Ed.), *Effortless attention: A new perspective in the cognitive science of attention and action* (pp. 29–49). MIT Press.

Schoendube, A., Bertrams, A., Sudeck, G., & Fuchs, R. (2017). Self-control strength and physical exercise: An ecological momentary assessment study. *Psychology of Sport and Exercise, 29*, 19–26. doi:10.1016/j.psychsport.2016.11.006

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: an integrative theory of anterior cingulate cortex function. *Neuron, 79*, 217–240. doi:10.1016/j.neuron.2013.07.007

Shenhav, A., Musslick, S., Lieder, F., Kool, W., Griffiths, T. L., Cohen, J. D., & Botvinick, M. M. (2017). Toward a rational and mechanistic account of mental effort. *Annual Review of Neuroscience, 40*, 99-124. doi: 10.1146/annurev-neuro-072116-031526

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662. doi:10.1037/h0054651

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality, 72*, 271–324. doi:10.1111/j.0022-3506.2004.00263.x

Thomson, D. R., Besner, D., & Smilek, D. (2015). A resource-control account of sustained attention: Evidence from mind-wandering and vigilance paradigms. *Perspectives on Psychological Science, 10*, 82–96. doi:10.1177/1745691614556681

Van Cutsem, J., Marcora, S., De Pauw, K., Bailey, S., Meeusen, R., & Roelands, B. (2017). The effects of mental fatigue on physical performance: A systematic review. *Sports Medicine, 47*, 1569–1588. doi: 10.1007/s40279-016-0672-0

Wagstaff, C. R. (2014). Emotion regulation and sport performance. *Journal of Sport and Exercise Psychology, 36*, 401–412. doi:10.1123/jsep.2013-0257

Wilson, M., Coleman, M., & McGrath, J. (2010). Developing basic hand–eye coordination skills for laparoscopic surgery using gaze training. *BJU Int*, *105*, 1356–1358. doi:10.1111/j.1464-410X.2010.09315.x

Wilson, M. R., Vine, S. J., & Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport and Exercise Psychology, 31*, 152–168. doi:10.1123/jsep.31.2.152

Wolff, W., Baumann, L., & Englert, C. (2018). Self-reports from behind the scenes: Questionable research practices and rates of replication in ego depletion research. *PLOS ONE, 13*(6), e0199554. doi:10.1371/journal.pone.0199554

Wolff, W., & Martarelli, C. (2020). Bored into depletion? Towards a tentative integration of perceived self-control exertion and boredom as guiding signals for goal-directed behavior. *Perspectives on Psychological Science*, forthcoming. doi:10.1177/1745691620921394

Wolff, W., Sieber, V., Bieleke, M., & Englert, C. (2019). Task duration and task order do not matter: No effect on self-control performance. *Psychological Research*, 1–11. doi:10.1007/s00426-019-01230-1

Tables

Table 1

Means, standard deviations, and internal consistencies of the German 5-Item Brief State Self Control Capacity Scale (SMS-5; Lindner et al., 2019) for each shooting block during the first and second shooting rounds.

Shooting block	First shooting round			Second shooting round		
	M	*SD*	α	*M*	*SD*	α
Baseline	5.62	0.84	.741	5.81	0.87	.849
1	5.36	0.89	.705	5.90	0.82	.781
2	5.36	0.93	.764	5.51	1.03	.850
3	5.00	1.23	.853	5.58	0.80	.745
4	4.91	1.14	.842	5.45	088	.816
5	4.75	1.37	.891	5.08	1.15	.832

Note. $N = 21$. Each item of the SMS-5 was answered on a scale from 1 (“not true”) to 7 (“very true”).

Figure Captions

Figure 1. *Changes in SCbase and Performance across blocks and the relationship between Performance and SCbase.* A) SCbase displayed as a function of shooting blocks. B) Shooting performance displayed as a function of shooting blocks. C) Shooting performance displayed as a function of SCbase. For all graphs, black points correspond to individual measurements, the blue line and area correspond to the posterior mean estimate and to the 95% upper and lower credible intervals respectively. To facilitate the reading of individual data points, a small horizontal random “jitter” was used.

Figure 2. *Effect of athletic group level on the relationship between self-control and performance.* A) Shooting performance across shooting blocks for both groups. B) SCpre across blocks for both groups. C) Shooting performance in the function of SCpre for both groups. Points correspond to individual measurements, lines and areas correspond to the posterior mean estimate and to the 95% upper and lower confidence intervals, respectively. For visual convenience, we set the *y*-axis boundaries closer, and 179, 139, and 95 individual measurements are located outside the *y*-axis boundaries in A), B), and C), respectively. These individual measurements can be seen in Figure 1.