Understanding and Interpreting the Effects of Prior Cognitive Exertion on Self-Regulation of Sport and Exercise Performance

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Everyone knows a person who never seems to falter when it comes to sport and exercise performance. This could be the early morning riser that never skips a run, or the professional athlete that always manages to give it their all until the final buzzer. Naturally, we often wonder what it is that enables these individuals to consistently achieve their goals and perform to the best of their abilities regardless of the circumstances. Self-regulation is a key facet underlying success in many aspects of life including sport and exercise performance (Englert, 2016; Mischel et al., 2011; Moffitt et al., 2011). But why is it that so many people fail to self-regulate their behaviour in sport and exercise contexts? The cognitive demands we consistently face in society today may contribute to our struggles in this regard (Sterelny, 2007). In this chapter we will discuss the current state of self-regulation research in relation to sport and exercise performance with an emphasis on the deleterious carryover effects of exerting cognitive effort prior to task performance.

Self-regulation broadly refers to the processes of aligning a system’s current state with a desired end state or goal (Carver & Scheier, 2001). Humans regulate their thoughts, emotions, and behaviours continuously over the course of a day to maintain healthy diets, work and academic performance, and regular physical activity patterns (Hofmann et al., 2012). For example, striving to achieve a goal to exercise after work is an act of self-regulation (e.g., Buckley et al., 2014) that often requires resisting competing temptations such as watching television or hanging out with friends. Self-regulation processes are also engaged when performing various sport and exercise-based tasks including managing feelings of pain and fatigue while running in order to achieve a desired time (Wagstaff, 2014) or ignoring distracting fans when shooting a free throw (Englert et al., 2015). Thus, self-regulation is a broad process that aids in goal achievement across a diverse range of behaviours.

Self-control, however, refers to conscious, deliberate, and effortful processes that aid in the regulation of behaviour toward a desired end state or goal (Baumeister et al., 2007; Inzlicht et al., 2020). Simply stated, self-control is engaged in the self-regulation process when an event has the potential to direct our behaviour out of line with our broader goals. While the terms self-regulation and self-control are often used interchangeably (e.g., Baumeister & Vohs, 2016), others have suggested that self-regulation and self-control refer to distinct processes (e.g., Inzlicht et al., 2020), with self-control often subserving self-regulation. For instance, building off the examples above, self-control would be specifically engaged when resisting temptations to watch television and hang out with friends as well to ignore distracting fans and to cope with feelings of fatigue in order to maintain pace during a run. In these instances, and many others, self-control helps people self-regulate their behaviour. As such, self-regulation and self-control are interrelated processes that allow people to achieve their goals and, ultimately, live healthier, longer, and more prosperous lives (Baumeister et al., 1994; de Ridder et al., 2012; Mischel et al., 2011; Moffitt et al., 2011).

Given the above, we use the term self-regulation throughout this chapter as it is a broad term that encapsulates self-control processes in relation to sport and exercise performance. Indeed, the physical outcomes we review refer to acts of self-regulation whereby researchers ask participants to "*do their best*" (e.g., exercise for as long as they can, perform as many repetitions as possible, hit as many shots as possible) which requires acute acts of self-control (e.g., inhibiting pain and fatigue in order to persist, resisting the temptation to quit, managing distractions) to strive towards their overarching goal for the experimental session. Although the importance of self-regulation for achieving various adaptive physical and mental health outcomes is well understood, exerting self-regulation can be an effortful process and failures are common (Baumeister et al., 1994). This observation led to the development and refinement of several models and theories to help us understand why the prolonged exertion of self-regulation often leads to lapses in subsequent attempts to exert self-regulation across an array of behaviours, including sport and exercise performance.

In this chapter, we first review two of the most common models that have been used to understand self-regulatory processes as they relate to sport and exercise performance. We then discuss our current understanding of the effects of prior cognitive exertion on subsequent self-regulation of sport and exercise performance. The next section highlights intermediary processes that explain why sport and exercise performance is impaired following effortful cognitive exertion, in addition to factors known to mediate and moderate this relationship. Finally, we will close with briefly discussing future directions that will help improve the quality of this body of research, our knowledge about how these effects unfold in daily life, and techniques that will help us better understand the mechanisms underlying this relationship.

Models of Self-Regulation in Sport and Exercise

While research on self-regulation and self-control has garnered significant attention over the last 50 years across the broader discipline of psychology, research dedicated to understanding the importance of self-regulation for sport and exercise performance has only emerged within the last decade or so. Indeed, pioneering research within the areas of sport and exercise psychology (Bray et al., 2008) and exercise physiology (Marcora et al., 2009) has shown that exerting self-regulation for a brief or prolonged period of time (i.e., through a cognitive manipulation) negatively impairs subsequent physical task performance. The notion that performing a cognitive task requiring self-regulation has negative carryover effects on sport and exercise performance sparked considerable interest in this field of study (see Figures 1 and 2 and Tables 1a-c)[1]. However, differences in the areas in which this question has been investigated – psychology/sport and exercise psychology or physiology – has led to the emergence of two distinct perspectives in which these findings are understood. Specifically, sport and exercise psychologists have generally interpreted their findings within a resource-based model which contends that performance is impaired due to a state of "ego depletion" (Englert, 2016). On the other hand, exercise physiologists have interpreted their results within a motivation-based model that argues performance is impaired due to state of "mental fatigue" (e.g., Marcora et al., 2009). Despite similarities in study designs, cognitive manipulations (including their associated symptoms), the resultant state following these manipulations (Pattyn et al., 2018), and tasks used to assess a variety of sport and exercise-related performance outcomes, these approaches have evolved for the most part in isolation.

--- *Insert Figures 1 and 2 here* ---

--- *Insert Tables 1a-c here* ---

Below we have provided reviews of the two models most commonly adopted to interpret findings from studies that have investigated self-regulation of sport and exercise performance following exposure to an initial task requiring effortful cognitive exertion.

[1] Studies appearing in Tables 1a-c and Figures 1 and 2 adhered to the eligibility criteria and search terms used by Brown et al. (2020) which reviewed studies that investigated the carryover effects of cognitive exertion on physical performance without including any other manipulations (e.g., motivational incentives, performance at high altitude). True control and experimental conditions (i.e., the no manipulation conditions) were pulled from studies that included auxiliary manipulations, although in some cases this was not possible, and these studies were not included in these Tables and Figures. Some examples are included in the "Potential Mediators and Moderators of Performance" and "Future Directions" subsections near the end of this chapter.

Strength Model of Self-Regulation

Self-regulation research within sport and exercise psychology has been informed largely by the strength model of self-regulation (Baumeister et al., 1998; Baumeister & Vohs, 2016). Given the observation that self-regulation failures are commonplace (Baumeister et al., 1994), Baumeister and colleagues hypothesized that our ability to use (or exert) self-regulation is based on a limited store of internal resources. That is, when self-regulation is used for a prolonged period to regulate thoughts, emotions, or behaviours: it depletes this internal reserve of resources leaving less resources available for subsequent acts of self-regulation. Baumeister and colleagues introduced the term *ego depletion* to describe the altered psychophysiological state that is brought on following the prolonged exertion of self-regulation. Ego depletion refers to "*a temporary reduction in the self's capacity or willingness to engage in volitional action (including controlling the environment, controlling the self, making choices, and initiating action) caused by exercise of volition* (Baumeister et al., 1998, p. 1253)". Therefore, when people are in a state of ego depletion, self-regulation failures are theoretically more likely to occur.

Ego depletion has been commonly studied using either a dual task paradigm that requires participants to perform two tasks in succession or a multiple task paradigm that requires participants to perform three (or more) tasks in succession. In the dual task paradigm, participants in the control condition perform an initial task that requires little (or no) self-regulation to perform (e.g., freely able to eat candy), whereas participants in the experimental condition perform a harder version of the task that requires a higher degree of self-regulation to perform (e.g., resisting the temptation to eat candy) and thus, induces a state of ego depletion (e.g., Baumeister et al., 1998). Following the initial task, all participants then perform a task that requires a high degree of self-regulation to perform (e.g., trying to solve an impossible maze or puzzle) and the performance on this task serves as the outcome measure of self-regulation. If self-regulation is based on a limited amount of resources, Baumeister and colleagues (1998) assumed that participants in the experimental condition would perform worse on the second task when compared to participants in the control condition as they had less self-regulatory resources to drawn upon due to expending them on the first task.

In an illustrative example of the multiple task paradigm (Muraven et al., 1998, Study 1), all participants completed an initial physical endurance task that required participants to hold a wad of paper between the handles of a spring-loaded handgrip exerciser (i.e., by squeezing the handles tightly) for as long as possible. All of the participants then watched a documentary for 3-minutes. Participants in the control condition were simply instructed to watch the movie. Participants in one experimental condition were instructed to increase their emotional response to the movie as much as possible, whereas those in a second experimental condition were told to decrease (or suppress) their emotional response to the movie as much as possible. Following the movie, all of the participants performed another endurance handgrip task and the change in the time they were able to persist holding the handgrip served as the outcome measure of self-regulation. Participants in the experimental conditions were hypothesized to perform worse on the second handgrip trial as they had less resources to draw upon following the emotion regulation manipulation. Consistent with their hypotheses, participants who regulated their emotions squeezed the handgrip for less time on the second handgrip trial when compared to the first, whereas control participants' performance remained relatively stable across trials.

Findings from Baumeister and colleagues' early set of experiments seemed to support the idea that self-regulation relies on a limited resource (Baumeister et al., 1998; Muraven et al., 1998). That is, participants who initially exerted a high degree of self-regulation to control their thoughts, emotions, or behaviours tended to perform worse on a subsequent test of self-regulation (across an array of tasks) when compared to control participants who were able to freely self-regulate themselves initially (Hagger et al., 2010). While this early work sparked significant interest (over 600 studies) across many disciplines investigating an array of behaviours associated with failures at self-regulation (e.g., aggression, impulsive spending, alcohol and drug use), it was not until roughly a decade after the first handgrip study by (Muraven et al., 1998) that studies drawing from theorizing within the strength model began examining potential negative carryover effects of prolonged self-regulation exertion on sport and exercise-related outcomes.

While Baumeister and colleagues were not necessarily interested in physical task performance outcomes as they relate to sport and exercise behaviour, they recognized certain aspects of these behaviours such as enduring physical discomfort or muscle fatigue also require self-regulation and, in turn, task performance may be sensitive to ego depletion effects. In the first controlled lab-based study to examine this idea, Bray et al. (2008) used a similar design to Muraven et al. (1998) that involved two isometric endurance handgrip squeezes – but this time using a calibrated handgrip dynamometer – separated by a cognitive self-regulation manipulation (i.e., Stroop task; Stroop, 1935). Participants in the experimental condition performed a modified incongruent version of the Stroop task, whereas control participants performed the congruent version of the Stroop task. In both versions, participants were presented with lists of colour words. In the congruent version, the text and the ink colour of the words were matched (e.g., the word "*yellow*" was printed in yellow ink) and participants were asked to read aloud the word presented (i.e., yellow). In the incongruent version, the text and ink colour of the words were mismatched (e.g., the word *"yellow*" was printed in green ink) and participants were asked to say aloud colour of the print ink (i.e., green) while ignoring the text for each word presented. In addition, experimental participants were asked to override these general rules and read aloud the printed text of each word presented in red ink (e.g., the word "*yellow*" was printed in red ink, and so participants had to say "yellow" instead of "red"). Findings from Bray et al. (2008) replicated initial work by Muraven et al. (1998) showing participants who exerted a high degree of self-regulation to perform an incongruent version of the Stroop task (experimental condition) persisted for less time on the second handgrip endurance trial (when compared to their first endurance trial). In comparison, participants who completed the easier congruent version of the Stroop task (control condition) did not show any decrements in performance on the second endurance trial. Subsequent work has shown ego depletion effects across a range of aerobic, resistance, and isometric tasks requiring physical endurance (see Table 1b) including cycling (Martin Ginis & Bray, 2010), push-ups and sit-ups (Dorris et al., 2012), bench press and leg extension (Graham et al., 2017), and wall-sits (Boat & Taylor, 2017).

Based on the notion that self-regulation resources are limited in nature, it is relatively easy to understand how a prior act of self-regulation can negatively affect subsequent physical endurance performance. That is, when in a state of ego depletion, people's ability to endure pain and fatigue is compromised and so they give up sooner. Furthermore research also suggests that ego depletion negatively affects people's ability to selectively regulate their attention (Schmeichel & Baumeister, 2010). These findings led to work investigating ego depletion effects across various motor-based sport and exercise-related tasks where attentional control is crucial for successful performance (see Table 1b). For instance, ego depletion negatively affects dart throwing accuracy (McEwan et al., 2013), sprint start reaction time (Englert & Bertrams, 2014) and basketball free throw shooting accuracy (Englert, Bertrams, et al., 2015). In addition, even controlling one's exercise related thoughts using a popular sport and exercise psychology technique (i.e., mental imagery) can also induce ego depletion and negatively affect aspects of physical performance (Graham et al., 2014). Although most of the research examining ego depletion effects has been conducted with young adults, ego depletion has also been shown to negatively affect physical performance among older adults (Bray et al., 2011) and children (Graham et al., 2018).

Taken together, ample research shows that prior exertion of self-regulation negatively affects physical performance across a diverse range of sport and exercise-related tasks and age groups. Based on the strength model, researchers have generally assumed that these performance decrements are primarily due to self-regulation resources being depleted on the first task leaving less resources available to draw upon on the second task. However, this is still an assumption as researchers have struggled to identify where these resources manifest in the human body and how to properly measure them. In turn, much debate and concern has evolved over the application of the strength model when examining the aftereffects of self-regulation exertion on physical performance.

Considerations and Pitfalls. Support for the strength model comes from over 300 independent studies among the broader psychology literature showing initial self-regulatory exertion impairs self-regulation on a subsequent task (Dang, 2018). Of particular relevance to the present chapter is that these effects have been observed across a variety of physical tasks in over 50 studies involving participants of different ages and expertise levels (see Tables 1b and 1c). However, evidence in the broader ego depletion literature has since emerged that is incompatible with a resource-based account of self-regulation, bringing the strength model into question (Beedie & Lane, 2012; Molden et al., 2012).

While the strength model provides an intuitive explanation often likened to muscle fatigue for why ego depletion occurs, research has identified three primary concerns that challenge this model. Perhaps the most concerning issue that has been raised surrounds the proposed underlying depletable mechanism. Despite an abundance of research attempting to uncover a biologically based "resource" (e.g., Gailliot & Baumeister, 2007), the origin as well as methods to measure or operationalize the state of the resource outlined within the strength model of self-regulation remains unknown (Friese et al., 2019). Given that a central resource is identified as the mechanism driving these effects, without having a mechanism to test, the strength model is virtually unfalsifiable – a characteristic of a poor theory (see Gieseler et al., 2019). The second challenge to the strength model comes from work showing that manipulating motivation can attenuate ego depletion effects (e.g., Brown & Bray, 2017b; Luethi et al., 2016; Muraven & Slessareva, 2003). For instance, Brown and Bray (2017b) showed that offering a performance contingent incentive to depleted participants can restore handgrip endurance performance to levels achieved in a non-depleted state. To accommodate these findings within the strength model, Baumeister and Vohs (2016) have argued people do not exhaust their resources completely on the initial self-regulatory task and simply dig deeper into their resource stores when adequately motivated. But this still assumes that a central resource exists. The final challenge to the strength model involves studies that have manipulated people's beliefs and perceptions. That is, when people believe willpower is unlimited (Job et al., 2010, 2013, 2015; Martijn et al., 2002) or feel invigorated following self-regulatory exertion (Clarkson et al., 2010), typical ego depletion effects are not observed.

Collectively, these findings have fueled considerable criticism of the strength model and whether a resource-based account is the appropriate explanation for why we often experience self-regulatory lapses after performing an initial task requiring self-regulation. This has prompted alternative theorizing that self-regulation is not dependent upon a resource, but on motivation and a reasoned assessment of benefits and costs of one's response alternatives (Inzlicht & Schmeichel, 2012; Kotabe & Hofmann, 2015; Kurzban et al., 2013). Although motivational accounts of self-regulation have received limited attention in the sport and exercise domain to date, prominent theories such as the shifting priorities model of self-control failure[2] provide mechanistic approaches that can and should be tested in this domain (Inzlicht et al., 2014; Inzlicht & Schmeichel, 2012; Milyavskaya & Inzlicht, 2017).

Whether an ego depletion effect actually exists has also been significantly debated with some suggesting ego depletion does not exist, and if it does, the effect is small (for recent examples see Baumeister, 2019; Baumeister & Vohs, 2016; Carter et al., 2015; Cunningham & Baumeister, 2016; Dang, 2018; Dang et al., 2020; Friese et al., 2019; Hagger et al., 2016; Inzlicht & Friese, 2019). Despite the controversy of whether an ego depletion effect exists based on previous meta-analyses (Carter et al., 2015; Carter & McCullough, 2014; Dang, 2018) and multi-site replication attempts (Dang et al., 2020; Hagger et al., 2016), it is critical to note several limitations with regards to the conclusions drawn from these studies as they pertain to sport and exercise performance. For instance, although some of the meta-analyses included studies examining physical outcomes, none conducted a sub analysis that quantified the magnitude of the ego depletion effect on sport and exercise performance, which discounts the possibility that ego depletion may vary across domains (e.g., cognitive versus physical

[2] The shifting priorities model was originally known as the process model of ego depletion (Inzlicht et al., 2014; Inzlicht & Schmeichel, 2012)

outcomes). In addition, while the results are mixed from multi-lab replication studies (Dang et al., 2020; Hagger et al., 2016), these attempts did not involve a physical task as the outcome measure. Therefore, the findings and conclusions drawn from recent meta-analyses, multi-site replication attempts, and commentaries need to be interpreted with caution when inferring about sport and exercise performance. In fact, meta-analyses of studies that have examined ego depletion (or mental fatigue) strictly in a sport and exercise context have found evidence of small (g = -0.38; Brown et al., 2020) and moderate (ES = -0.506; Giboin & Wolff, 2019) sized deleterious effects.

Psychobiological Model

While there has been much debate over whether resource or motivation-based models best explain self-regulatory behaviour more broadly, these theories lack specificity with regards to factors inherently unique to sport and exercise performance. Consider going for a run. Most people would agree that one of the most salient factors while running is their perception of physical exertion and that these sensations largely influence our decisions regarding whether to speed up, slow down, give up or keep going (Staiano et al., 2018). Physical exertion and the sensations that accompany the effort required to move are unique characteristics of sport and exercise performance that influence self-regulation of this behaviour. Roughly a decade after the first self-regulation studies were published, including some that involved physical endurance tasks (e.g., isometric handgrip squeeze; Muraven et al., 1998), the psychobiological model emerged as an effort-based decision-making theory to explain exercise tolerance (Marcora, 2008; Marcora et al., 2008, 2009; Marcora & Staiano, 2010). Although the psychobiological model was originally designed to explain how both physiological and psychological factors influence self-regulation of exercise performance, this model has received significant attention for its ability to explain the effects of prior cognitive exertion on self-regulation of sport and exercise performance.

Rooted in motivational intensity theory (Brehm & Self, 1989), the psychobiological model posits that exercise-induced fatigue (e.g., task disengagement or reduced intensity) is not simply due to physiological exhaustion, but rather a conscious decision driven by the interplay between two factors: 1) perception of effort, and 2) potential motivation. Perception of effort refers to the conscious sensations of how hard, heavy or strenuous an individual perceives a physical task to be (Marcora, 2010). On the other hand, potential motivation refers to the maximum effort an individual is willing to exert to attain their goal (Wright, 2008). Considered together, the psychobiological model predicts that individuals decide to quit exercising or reduce their current level of effort because the effort required to continue at the current intensity exceeds their potential motivation or perceived ability to sustain such a level of effort. Support for this model stems from studies that have shown manipulating perception of effort (e.g., de Morree, Klein & Marcora, 2012) and potential motivation (e.g., Cabanac, 1986) can influence exercise performance independently from physiological mechanisms (i.e., cardiovascular, respiratory, metabolic, neuromuscular) assumed to underly exercise tolerance (Allen et al., 2008; Amann & Calbet, 2008; Burnley & Jones, 2007; McKenna & Hargreaves, 2008; Noakes & Gibson, 2004; Secher et al., 2008; Walsh, 2000). Despite exercise performance being proposed to be driven by the interplay between perception of effort and potential motivation, research has consistently shown a strong association between maximal perceptions of exertion and exercise termination, which supports the notion that perception of effort is the primary determinant of endurance/exercise performance (Crewe et al., 2008; Eston et al., 2007; Horstman et al., 1979;

Nakamura et al., 2008; Noakes, 2008). This has led to perception of effort being termed the "cardinal exercise stopper" (Staiano et al., 2018).

The psychobiological model also recognizes that various factors can affect exercise performance through influencing perception of effort and/or potential motivation. Of relevance to the focus of the present chapter, mental fatigue has been found to influence self-regulation of exercise performance through its impact on perceived exertion (see Van Cutsem et al., 2017 for a review). Mental fatigue refers to a complex psychophysiological phenomenon that results in feelings of tiredness or lack of energy following exposure to tasks that require prolonged cognitive exertion (Boksem & Tops, 2008). It is through this indirect pathway that the psychobiological model has been applied to understand the effects of prior cognitive exertion on exercise performance. Evidence in support of this line of theorizing began to materialize shortly after the psychobiological model was proposed. The seminal study investigating the effects of mental fatigue on aerobic endurance performance was a within-subject crossover trial that involved 16 participants cycling to exhaustion at 80% of their peak power output after performing a demanding cognitive task (i.e., continuous performance task – AX version; AX-CPT) or watching a documentary for 90 minutes (Marcora et al., 2009). In the AX-CPT, cue-probe sequences consisting of four letters are continuously presented on a screen. Each cue-probe sequence involves presentation of a red cue letter first, followed by two white distractor letters, and finishing with a red probe letter. Participants are instructed to respond whether a target (A appears as cue; X appears as probe) or non-target (any other cue-probe combination) trial appears. This task involves higher order cognitive control and sustained attention. Significant declines in vigor were observed following both experimental manipulations, however, participants only reported significant increases in fatigue after performing the demanding cognitive task. With regards to exercise performance, the results showed that participants quit exercising significantly earlier after completing the demanding cognitive task. Closer inspection of the data revealed high levels of motivation prior to exercising that were relatively equivalent between the conditions, thus ruling out motivation as an influential factor. However, during exercise, participants reached their maximal level of perceived exertion earlier following the demanding cognitive task (i.e., in a mentally fatigued state) despite no observed differences in the peripheral physiological responses (e.g., heart rate, oxygen consumption) that were assessed. In the time since this publication, several more studies have shown similar effects at different intensities across a variety of exercise modalities including self-paced aerobic exercise (e.g., Brown & Bray, 2019b; Brownsberger et al., 2013; MacMahon et al., 2014) and resistance exercise (e.g., Head et al., 2016; Pageaux et al., 2013) (see Table 1a). Taken together, these findings further support Marcora et al.'s (2009) conclusions that perceived effort is the key intermediary variable driving the effects of mental fatigue of exercise performance and highlight the ability of the psychobiological model to explain the mental fatigue–exercise performance relationship.

Although the psychobiological model accounts for the indirect effects of mental fatigue on exercise performance through increases in perception of effort, initial theorizing was broad and as a result, failed to identify mechanisms by which psychological factors such as mental fatigue would exacerbate perception of effort. Drawing on their results, Marcora et al. (2009) suggested mental fatigue disrupts central processing of the corollary discharge associated with the central motor command. This means that, when in a state of mental fatigue, a greater central motor command is necessary to produce the same force output as when not in a state of mental fatigue and, as a result, an increase in perception of exertion is experienced. The authors proposed the anterior cingulate cortex (ACC) likely plays a significant role in this process due to its involvement in motor control, emotion (i.e., perception of effort) and higher order cognitive functions involved in effort-related decision making. However, research to date has yet to test this theory in its totality.

After Marcora et al. (2009) demonstrated convincing evidence that exposure to a cognitively demanding task can impair subsequent self-regulation of exercise performance, several academics turned their attention to this area given the implications for sport. Naturally, this involved conducting studies to test boundary conditions of the mental fatigue–exercise performance relationship, but this also spurred further theorizing around the mechanisms by which mental fatigue may affect perception of effort and/or potential motivation. As emerging evidence continues to indicate physiological variables traditionally believed to limit endurance performance are unaffected by mental fatigue, extensions of the psychobiological model have focused on brain-based mechanisms. The first extension of the psychobiological model provided a neurobiological explanation focused on how mental fatigue influences perception of effort (Pageaux et al., 2014). Specifically, Pageaux et al. (2014) proposed that performing a demanding cognitive task leads to an accumulation of extracellular adenosine within the ACC, and in turn, exacerbates perceptions of effort. These predictions were based on research showing the ACC is activated while performing cognitive tasks (Bush et al., 2000; Swick & Jovanovic, 2002), including those commonly used to induce a state of mental fatigue (e.g., AX-CPT, Stroop task), and involved in perception of effort during exercise (Williamson et al., 2001, 2002). While this extension of the psychobiological model provides an interesting and plausible physiological explanation of how mental fatigue elicits a deleterious effect on exercise performance through increased perception of effort, there is one major shortcoming that needs to be acknowledged.

That is, the psychobiological model posits that the interplay between perception of effort and potential motivation drives exercise performance; thus, the neurobiological explanation put forth by Pageaux et al. (2014) fails to consider the totality of the model in that it ignores the role of potential motivation.

Martin et al. (2018) have since extended upon the initial physiological explanation proposed by Pageaux et al. (2014). Importantly, this updated physiological explanation encompasses both central tenets of the psychobiological model: accounting for how mental fatigue affects exercise performance through not only affecting perception of exertion, but also potential motivation. Adenosine was again identified as the key mechanism driving this cascade of events. In addition to adenosine accumulation causing increased perception of effort, Martin et al. (2018) proposed a second pathway by which the buildup of adenosine due to effortful cognitive engagement inhibits the release of dopamine within the ACC, and in turn reduces one's motivation to exert further effort. This intuitive proposition is centred around neuroanatomical research and experimental work involving reward sensitivity and decision making among animal models (Fredholm & Svenningsson, 2003; Salamone et al., 2018; Schweimer & Hauber, 2006; Stanwood et al., 2001). Although Martin et al.'s (2018) physiological explanation is all encompassing with regards to the central constructs identified within the psychobiological model, it has not been tested within humans and would be challenging to do so.

The revised physiological explanation proposed by Martin et al. (2018) also includes a notable conceptual overlap with the strength model of self-regulation. According to their model, Martin et al. (2018) suggest effortful cognitive exertion depletes localized cerebral fuel stores and in turn produces a bi-product: cerebral adenosine. This line of theorizing was informed by a study comparing exercise performance following exposure to a mentally fatiguing cognitive task between recreational and professional cyclists (Martin et al., 2016). The results showed professional cyclists made less errors on a response inhibition task (i.e., Stroop task) than recreational cyclists and were resilient to the effects of prior cognitive exertion on a subsequent cycling task, whereas recreational cyclists demonstrated a significant decline in performance. Martin et al. (2018) have interpreted these findings as potential genetic or training-induced adaptations that provide superior inhibitory control due to increased neuronal efficiency. That is, those with greater neuronal efficiency would use less “cerebral fuel” during tasks involving mental exertion, and as a result, have less adenosine accumulation. This would have a twofold effect where perception of effort and potential motivation are both affected to a lesser extent, ultimately contributing to superior exercise performance. Overall, Martin et al.'s (2018) extended physiological explanation of the psychobiological model provides a more thorough account of how mental fatigue impairs subsequent self-regulation of exercise performance through an intuitive multi-process pathway.

***Considerations and Pitfalls*.** Evidence to date in support of the psychobiological model overwhelmingly indicates perception of effort is the primary driver of exercise performance following exposure to mental exertion (Van Cutsem et al., 2017). Since Marcora et al.'s (2009) seminal findings were published, studies have shown the characteristics of the exercise task (e.g., fixed vs. variable demand) shape behavioural responses to mental fatigue through perception of effort. For tasks involving fixed demands such as cycling to exhaustion, perception of effort is the “cardinal exercise stopper” whereby individuals tend to give up once they have reached the peak perception of effort they are willing to tolerate (Staiano et al., 2018). This peak is reached sooner in a mentally fatigued state. In contrast, for variable demand exercise tasks in which individuals can adjust their pace (e.g., running a 5km race), perception of effort may be considered the “cardinal effort regulator”. In this case, when perception of effort is exacerbated due to mental fatigue, individuals simply down-regulate their pace to bring their perception of effort in line with what they would typically experience in an optimal state. Taken together, findings support theorizing of the psychobiological model in which perception of effort plays a central role in performance of exercise tasks involving prolonged effortful exertion.

On the other hand, and similar to findings discussed in the previous section, research to date has shown limited support for the motivational component of the psychobiological model. Studies have assessed various forms of motivation (e.g., task, success, intrinsic) but for the most part have failed to detect any motivational shifts that can be attributed to mental fatigue. As noted previously (Brown & Bray, 2019b; Martin et al., 2018), measures of motivation may be too broad or abstract to objectively quantify shifts in motivation that occur when people are mentally fatigued. Measures of motivation are also confounded by the voluntary nature of participation in research: participants often come into the lab highly motivated to perform the task at hand, often leading to ceiling effects when reporting motivation. This issue has been brought to attention by Martin et al. (2018). Moving forward, we need to gain a better understanding of how motivation affects self-regulation of exercise performance if we are to unanimously adopt the psychobiological model to understand the effects of prior cognitive exertion on exercise performance.

Finally, recent extensions of the psychobiological model have provided an intuitive physiological explanation for why mental fatigue has a deleterious effect on sport and exercise performance through influencing perception of effort and potential motivation (Martin et al., 2018; Pageaux, 2014). These propositions have focused primarily on neurobiological processes involving adenosine accumulation and more recently, inhibition of dopamine release. However, the pathways outlined in these physiological explanations are based on research investigating animal models and have yet to be tested in humans. While we can infer about this relationship from findings using animal models, the neurobiological pathways by which this phenomenon occurs in humans is currently unknown. It is apparent that we will need methodological advances in neurobiological measurement before we can comprehensively test this model in humans.

Where do we Currently Stand?

As noted earlier in this chapter, research investigating self-regulation of sport and exercise performance following an initial task involving cognitive exertion has been conceptualized as due to either ego depletion or mental fatigue. Within these emerging bodies of literature, there have been several recent efforts to synthesize current evidence through conducting systematic reviews (Englert, 2016; Pageaux & Lepers, 2018; Silva-Júnior et al., 2016; Van Cutsem et al., 2017) and meta-analyses (Brown et al., 2020; Giboin & Wolff, 2019; McMorris et al., 2018). Studies from both areas have generally concluded that performing an initial demanding cognitive task leads to subsequent performance impairments across a broad range of aerobic and resistance-based tasks that require prolonged effort regulation, in addition to sport-specific motor tasks. In the first attempt to quantify the magnitude and direction of the effects of prior cognitive exertion on subsequent physical performance, McMorris et al. (2018) demonstrated a small negative effect (g = -0.26), although statistical tests suggested this effect may be due to random error. However, these results were only drawn from studies that examined mental (or cognitive) fatigue, which resulted in only eight studies being included. Significant concerns have since been expressed regarding the comprehensiveness and replicability of their search, as well as the rationale for their exclusion criteria (Magariño & Madhivanan, 2019). Therefore, considering the substantial methodological similarities between ego depletion and mental fatigue studies, the meta-analysis of McMorris et al. (2018) failed to consider what is a much larger body of literature.

The major difference that has been argued to stand between the unification of the mental fatigue and ego depletion literatures has been the duration of the cognitive manipulations (Englert, 2016; Pageaux et al., 2013; Van Cutsem et al., 2017). Most mental fatigue studies have used cognitive manipulations lasting 30 minutes or more (e.g., Marcora et al., 2009), whereas ego depletion studies typically use manipulations of shorter duration, with some as brief as 3.5 minutes (e.g., Bray et al., 2008). Researchers examining mental fatigue have argued the cognitive manipulations employed to cause ego depletion are too brief to induce a state of mental fatigue (Pageaux et al., 2013). Simply stated, only after prolonged mental exertion can mental fatigue be experienced. In their recent review, Van Cutsem et al. (2017) argued the minimum task duration necessary to induce mental fatigue is 30 minutes. This claim was based on studies showing decrements in vigilance (Nuechterlein et al., 1983) and increases in mental fatigue occurring around the 30 minute time point (Smith, Coutts, et al., 2016). Van Cutsem et al. (2017) also argued against including research from the ego depletion area due to a replication crisis. Unfortunately, the evidence upon which this 30-minute point is based on is both weak and suspect for two reasons. First, only a small proportion of studies in the ego depletion literature have investigated effects of cognitive exertion on physical performance and none of the failed replication efforts undertaken thus far have involved effects of cognitive tasks on physical tasks. Second, it fails to recognize multiple ego depletion studies that have documented significant increases in self-reported mental fatigue following cognitive manipulations lasting much less than 30-minutes (e.g., Bray et al., 2011; Brown & Bray, 2017a, 2019a; Graham & Bray, 2012; Muraven et al., 1998). These findings have led theorists to posit ego depletion is a form of mental fatigue (Hagger et al., 2010; Inzlicht & Berkman, 2015). In addition to task duration, there is compelling evidence that the difficulty of a cognitive task also contributes to perceptions of mental fatigue. That is, difficult cognitive tasks can result in high levels of fatigue in a fraction of the time required by less difficult cognitive tasks (Boksem & Tops, 2008; Mackworth, 1964; Warm et al., 2008). For example, performing a highly demanding Stroop task for 10-minutes (Brown & Bray, 2017a) has been shown to produce similar levels of mental fatigue to engaging in a moderately demanding continuous performance task (i.e., AX-CPT) for 50-minutes (Brown & Bray, 2019b). In light of this evidence and the substantial overlap in methodologies, it makes sense to examine these bodies of literature together in totality.

To fully describe and interpret the greater body of literature examining the effects of prior cognitive exertion on self-regulation of sport and exercise performance, we undertook a comprehensive synthesis and meta-analysis that integrated the mental fatigue and ego depletion literatures (Brown et al., 2020). Our rigorous search of the literature found a total of 79 studies (which included 98 comparisons) that involved performance of a physical task following completion of an initial task requiring effortful cognitive exertion. Of the 79 studies, we were able to obtain sufficient statistical information to include 73 studies (which included 91 comparisons) in the meta-analysis.

The results of our meta-analysis of the effects of prior cognitive exertion on self-regulation of a subsequent physical performance task revealed a significant, small-to-medium sized negative overall effect (g = -0.38). Of the 91 independent comparisons included in the meta-analysis, 81 suggested evidence of a deleterious effect, of which 46 indicated a significant performance impairment (all *p's* < .05). Further statistical tests demonstrated significant heterogeneity in the data which led us to conclude that the observed effect is likely not due to chance. Another comprehensive meta-analysis of the ego depletion and mental fatigue literature reached a similar conclusion. Looking strictly at endurance performance, Giboin and Wolff (2019) found evidence of a significant medium-sized negative effect (ES = -0.506) across 42 independent comparisons. Therefore, by unifying ego depletion and mental fatigue studies to investigate this greater body of literature in its totality (Brown et al., 2020; Giboin & Wolff, 2019), these meta-analyses were able to reduce potential selection bias which may have influenced conclusions drawn by previous reviews and meta-analyses in the area.

Beyond providing a comprehensive investigation of the overall effect of prior cognitive exertion on subsequent physical performance, our meta-analysis included a closer look at several potential moderators of this relationship. One of the most important subgroup analyses pertained to the aforementioned differences in cognitive manipulation durations used in studies aiming to induce a state of ego depletion or mental fatigue. Given that 30-minutes has been suggested to be the minimum duration needed to induce a state of mental fatigue and in turn impair physical performance (Van Cutsem et al., 2017), we stratified studies into two groups based on the duration of the cognitive manipulation utilized: those < 30-minutes, and those ≥ 30-minutes. The results of our subgroup analysis failed to reveal a difference between the two groups. Simply stated, cognitive manipulations lasting less than 30-minutes ($g = -0.45$) and those lasting 30-minutes or longer ($g = -0.30$) had similar small-to-medium sized negative carryover effects on physical performance. However, using this arbitrary cut-point failed to consider the possibility of a potential dose-response relationship. To explore this issue, we conducted a post-hoc meta-regression of the relationship between cognitive task duration and physical performance. The results did not support a linear dose-response relationship. Taken together, evidence suggests time on task may not be the driving factor underlying subsequent self-regulatory impairments.

Another major advance provided by our meta-analysis was the quantification of the effects of prior cognitive exertion on different types of sport and exercise tasks. Our study built upon previous findings of a qualitative synthesis of the effects of prior cognitive exertion on a variety of sport and exercise performance outcomes (Pageaux & Lepers, 2018). In their review, Pageaux and Lepers (2018) concluded that tasks requiring precision (i.e., motor skills) or sustained regulation of effort (i.e., aerobic, dynamic resistance, isometric resistance performance) are most sensitive to prior cognitive exertion, whereas performance of tasks requiring maximal anaerobic performance such as a sprint, appear unaffected. The results from our meta-analysis provide statistical support for these findings. Specifically, we found prior cognitive exertion to have significant negative effects on motor performance (g = -0.57) and tasks requiring prolonged effort regulation (i.e., aerobic [g = -0.26], isometric resistance [g = -0.57], dynamic resistance performance [g = -0.51]).Tasks requiring maximal anaerobic performance showed trivial effects that were not significant. Similar effects have also been reported for endurance tasks grouped based on whether they involved an isolated group of muscles (e.g., handgrip squeeze; ES = -0.719) or the whole body (e.g., cycling; coefficient = 0.338) (Giboin & Wolff, 2019).

The physiological model proposed by Martin et al. (2018) provides an explanation for why prior cognitive exertion negatively affects tasks involving the sustained regulation of effort (i.e., aerobic, dynamic resistance, isometric resistance performance) to a greater extent than tasks involving maximal anerobic performance. That is, “all out” tasks requiring brief maximal anaerobic performance do not require pacing strategies; thus, individuals are able to endure higher perceptions of effort for short durations that would otherwise derail performance of longer tasks. Theorizing pertaining to the negative carryover effects of cognitive exertion on tasks requiring sustained attention and motor skills however, has received much less attention to date. Building off Martin et al.'s (2018) model, it is plausible that shared neural pathways governing cognition (e.g., attention) and motor behaviour become compromised due to extracellular increases in adenosine and the subsequent dysregulation of dopaminergic neurons governing motor skills, leading to a cascade of psychophysiological processes that affect physical task performance (Brown et al., 2020, p. 524; Graham et al., 2018, p. 11). Nevertheless, additional research is needed to investigate the effect of prior cognitive exertion on maximal anaerobic performance while also testing the aforementioned propositions for reductions in various types of physical task performance.

Potential Mediators and Moderators of Performance

Despite the consistent effects of prior cognitive exertion on self-regulation of sport and exercise performance, very few studies have examined potential mediators and moderators of performance. By identifying mediators and moderators we can build on theory to understand underlying mechanisms. For example, the shifting priorities (or process) model proposes self-regulation is the product of multiple psychological inputs – motivation, emotion and attention – that increase or decrease the value of exerting further effort (Inzlicht et al., 2014; Milyavskaya & Inzlicht, 2017). Understanding the role of these processes could provide insight for recreational exercisers and professional athletes regarding the structure or timing of their workouts and competitions as well as recommendations for coaches and trainers when instructing individuals performing effortful tasks in succession. But only one study to date has comprehensively tested the assumptions of the shifting priorities model within a sport or exercise context and evidence of mediation was not observed (Stocker et al., 2020). On its own, motivation has received much more attention. Evidence indicates manipulating motivation through providing performance contingent incentives (Brown & Bray, 2017a) and autonomy supportive instructions (Graham, Bray, et al., 2014) can attenuate the negative effects of prior cognitive exertion on physical performance. Therefore, in the right circumstances, individuals are able to overcome the negative aftereffects of cognitive exertion when they are sufficiently motivated to do so.

Studies have shown perceptions of fatigue (Marcora et al., 2009), affective valence (Brown & Bray, 2017a), and task self-efficacy (Brown & Bray, 2017a; Graham & Bray, 2015) are altered following cognitive exertion and likely contribute to alterations in one's ability to self-regulate their physical performance. Indeed, based on theorizing within self-efficacy theory (Bandura, 1997), Graham et al. (2017) tested single and sequential mediation pathways including perceptions of fatigue and self-efficacy. They found that cognitive exertion led to higher perceptions of fatigue which, in turn, led to lower perceptions of self-efficacy (i.e., less confident to perform the upcoming physical task), and ultimately reduced physical task performance. Other research has shown following cognitive exertion people plan to exert less effort on a subsequent test of physical performance which resulted in less work performed during the self-paced exercise session (Brown & Bray, 2019a, 2019b). Taken together, subjective and likely instinctive responses to cognitive exertion, such as increased perceptions of fatigue and reduced affect, seem to trigger a cascade of psychological and decisional processes (e.g., "*I feel tired and less confident in my ability to perform so I don't think I can work as hard on this upcoming physical test"*) that ultimately contribute to reduced physical task performance. Researchers, coaches, and trainers are encouraged to monitor these subjective experiences following cognitive exertion to not only understand why performance decrements occur but also to develop ways to intervene. In fact, recent work has shown that using a heart rate monitor to provide biofeedback to self-monitor performance can successfully attenuate the effects of prior cognitive exertion (Brown &

Bray, 2019a). Commonly used self-monitoring tools that track distance, pace and heart rate may be able to create a motivational structure in which feedback can be leveraged to drive goal-directed behaviour in alignment with previously held standards or intentions through enhanced self-efficacy.

As previously discussed, ratings of perceived exertion are a prominent construct within the psychobiological model and are a consistent predictor of physical task cessation and performance. However, it would be interesting to investigate whether certain alterations in psychological processes experienced prior to task performance lead to (i.e., mediate) or enhance (i.e., moderate) changes in perceived exertion during task performance. We encourage researchers to use freely accessible software such as PROCESS (Hayes, 2017) and MEMORE (Montoya & Hayes, 2017) to test for mediation and moderation in between-subject and within-subject study designs. By doing so we will begin to form a deeper understanding of the prior cognitive exertion – physical performance relationship.

Recent research has also begun to investigate various individual level factors that moderate the prior cognitive exertion – physical performance relationship. For example, while many of the studies investigating the negative aftereffects of cognitive exertion on physical performance have primarily involved inactive or recreationally active individuals, the findings with regards to highly trained individuals have been mixed. That is, recent research suggests that highly trained athletes or expert performers may not be as susceptible to physical performance decrements following cognitive exertion (Kosack et al., 2020; Martin et al., 2016). Other work in children suggests children with low levels of motor coordination experience even greater negative effects of cognitive exertion on physical performance whereas high levels of motor coordination seem to buffer against the negative effects typically observed (Graham et al., 2018).

Future Directions

There are several promising avenues for future research investigating the effects of prior cognitive exertion on physical exertion. First and foremost, more research is needed investigating cognitive exertion and the self-regulation of physical activity behaviour in everyday life outside of contrived lab environments. Of the handful of naturalistic studies that have been conducted using daily diaries and ecological momentary assessment thus far, it seems that self-control dwindles across the course of one's day and negatively impacts physical activity intentions and behaviour (Englert & Rummel, 2016; Finne et al., 2019; Pfeffer & Strobach, 2017; Rebar et al., 2018; Schöndube et al., 2017). However, additional research is needed using physical activity trackers alongside self-reported measures.

With regards to lab environments, there are several opportunities for refinement and future research. For instance, one of the major limitations idenfitied across studies within the Brown et al.'s (2020) risk-of-bias assessment was the lack of blinding procedures. Future research should employ double-blinding procedures whereby one experimenter delivers the cognitive manipulation and another administers the physical task. Crossover and/or multi-task (i.e., physical task-cognitive task-physical task) experimental designs are also encouraged so that change in performance on the physical task can be compared within individuals and between conditions. Similarily, standardizing the physical task to participants' strength (i.e., percent of maximum voluntary contraction) or ability levels should be utlized whenever possible. A familiaration session with the physical task is also encouraged. While there is a strong rationale for selecting the cognitive manipulations previously employed within this body of literature, future work should should also consider using cognitive manipulations with greater external validity such as playing video games or scrolling through social media platforms (e.g., Fortes et al., 2020).

Finally, undertaking studies involving additional neurophysiological measures alongside self-report measures is strongly encouraged. Theorizing and limited findings based on the strength model and the psychobiological model suggest that various psychological, neurophysiological, and physiological processes are altered during cognitive exertion as well as during subsequent task performance (Lopez et al., 2015; Martin et al., 2018). That is, alterations in muscle activity patterns (Bray et al., 2008; Brown & Bray, 2017b; Graham, Sonne, et al., 2014; Pageaux et al., 2014) and brain activation patterns (Brownsberger et al., 2013; Pires et al., 2018) have been observed following cognitive exertion and during physical task performance. In addition, as previously mentioned in the 'potential mediators and moderators of performance section', various alterations in psychological processes have also been observed following cognitive exertion and during task performance. It would be very interesting to examine psychological, neurophysiological, and physiological processes either concurrently or sequentially in an experiment to understand how changes in one process may lead to changes in another.

Conclusion

In this chapter, we provided an in-depth overview of the current state of the literature examining the influence of prior cognitive exertion on self-regulation of subsequent sport and exercise performance. We outlined the two most common theoretical perspectives that have been adopted to interpret this body of research, while also highlighting why effects from ego depletion and mental fatigue studies should be considered collectively. At present, research indicates prior cognitive exertion has a small-to-moderate sized negative effect on subsequent physical performance, however, this effect is not dependent on time, and is most pronounced for motor-based tasks and tasks requiring prolonged effort regulation (e.g., aerobic or resistance exercise). Research has shown the negative effects of prior cognitive exertion manifest before an individual even begins to exercise, and once they do get started, they can expect to experience exacerbated perceptions of effort. Intervention strategies aiming to overcome these effects may be most effective when targeting motivational processes. Moving forward, researchers need to design better studies that reduce bias, step outside the lab to tackle this question in the real world, and take a multidisciplinary approach to better understand the mechanisms underlying these effects.

References

Alberts, H. J. E. M., Martijn, C., & de Vries, N. K. (2011). Fighting self-control failure: Overcoming ego depletion by increasing self-awareness. *Journal of Experimental Social Psychology*, *47*, 58–62. https://doi.org/10.1016/j.jesp.2010.08.004

Alberts, H. J. E. M., Martijn, C., Greb, J., Merckelbach, H., & Vries, N. K. de. (2007). Carrying on or giving in: The role of automatic processes in overcoming ego depletion. *British Journal of Social Psychology*, *46*, 383–399. https://doi.org/10.1348/014466606X130111

Alberts, H. J. E. M., Martijn, C., Nievelstein, F., Jansen, A., & de Vries, N. K. (2008). Distracting the self: Shifting attention prevents ego depletion. *Self and Identity*, *7*, 322–334. https://doi.org/10.1080/15298860801987583

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: Cellular mechanisms. *Physiological Reviews*, *88*, 287–332. https://doi.org/10.1152/physrev.00015.2007

Amann, M., & Calbet, J. A. L. (2008). Convective oxygen transport and fatigue. *Journal of Applied Physiology*, *104*, 861–870. https://doi.org/10.1152/japplphysiol.01008.2007

Azevedo, R., Silva-Cavalcante, M. D., Gualano, B., Lima-Silva, A. E., & Bertuzzi, R. (2016). Effects of caffeine ingestion on endurance performance in mentally fatigued individuals. *European Journal of Applied Physiology*, *116*, 2293–2303. https://doi.org/10.1007/s00421-016-3483-y

Badin, O. O., Smith, M. R., Conte, D., & Coutts, A. J. (2016). Mental fatigue: Impairment of technical performance in small-sided soccer games. *International Journal of Sports Physiology and Performance*, *11*, 1100–1105. https://doi.org/10.1123/ijspp.2015-0710

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: W.H. Freeman and Company.

Baumeister, R. F. (2019). Self-control, ego depletion, and social psychology’s replication crisis [Preprint]. *PsyArXiv*. https://doi.org/10.31234/osf.io/uf3cn

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology*, 1252–1265. https://doi.org/10.1037/0022-3514.74.5.1252

Baumeister, R. F., Heatherton, T. F., & Tice, D. M. (1994). *Losing control: How and why people fail at self-regulation*. Academic Press.

Baumeister, R. F., & Vohs, K. D. (2016). Strength model of self-regulation as limited resource: Assessment, controversies, update. In J. M. Olson & M. P. Zanna (Eds.), *Advances in Experimental Social Psychology* (Vol. 54, pp. 67–127). Academic Press. https://doi.org/10.1016/bs.aesp.2016.04.001

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science*, *16*, 351–355. https://doi.org/10.1111/j.1467-8721.2007.00534.x

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. https://doi.org/10.1177/1088868311419817

Boat, R., Atkins, T., Davenport, N., & Cooper, S. (2018). Prior self-control exertion and perceptions of pain and motivation during a physically effortful task. In M. Sarkar & S. Marcora (Eds.), *Sport and the Brain: The Science of Preparing, Enduring and Winning, Part C* (Vol. 240, pp. 19–34). Academic Press. https://doi.org/10.1016/bs.pbr.2018.08.007

Boat, R., & Taylor, I. M. (2017). Prior self-control exertion and perceptions of pain during a physically demanding task. *Psychology of Sport and Exercise*, *33*, 1–6. https://doi.org/10.1016/j.psychsport.2017.07.005

Boat, R., Taylor, I. M., & Hulston, C. J. (2017). Self-control exertion and glucose supplementation prior to endurance performance. *Psychology of Sport and Exercise*, *29*, 103–110. https://doi.org/10.1016/j.psychsport.2016.12.007

Boksem, M. A. S., & Tops, M. (2008). Mental fatigue: Costs and benefits. *Brain Research Reviews*, *59*, 125–139. https://doi.org/10.1016/j.brainresrev.2008.07.001

Bray, S. R., Ginis, K. A. M., Hicks, A. L., & Woodgate, J. (2008). Effects of self-regulatory strength depletion on muscular performance and EMG activation. *Psychophysiology*, *45*, 337–343. https://doi.org/10.1111/j.1469-8986.2007.00625.x

Bray, S. R., Martin Ginis, K. A., & Woodgate, J. (2011). Self-regulatory strength depletion and muscle-endurance performance: A test of the limited-strength model in older adults. *Journal of Aging and Physical Activity*, *19*, 177–188. https://doi.org/10.1123/japa.19.3.177

Bray, S. R., Oliver, J. P., Graham, J. D., & Ginis, K. A. M. (2013). Music, emotion, and self-control: Does listening to uplifting music replenish self-control strength for exercise? *Journal of Applied Biobehavioral Research*, *18*, 156–173. https://doi.org/10.1111/jabr.12008

Brehm, J. W., & Self, A. (1989). The intensity of motivation. *Annual Reviews in Psychology*, *40*, 109–131. https://doi.org/10.1146/annurev.ps.40.020189.000545

Brown, D. M. Y., & Bray, S. R. (2017a). Graded increases in cognitive control exertion reveal a threshold effect on subsequent physical performance. *Sport, Exercise, and Performance Psychology*, *6,* 355–369. https://doi.org/10.1037/spy0000091

Brown, D. M. Y., & Bray, S. R. (2017b). Effects of mental fatigue on physical endurance performance and muscle activation are attenuated by monetary incentives. *Journal of Sport and Exercise Psychology*, *39*, 385–396. https://doi.org/10.1123/jsep.2017-0187

Brown, D. M. Y., & Bray, S. R. (2019a). Heart rate biofeedback attenuates effects of mental fatigue on exercise performance. *Psychology of Sport and Exercise*, *41*, 70–79. https://doi.org/10.1016/j.psychsport.2018.12.001

Brown, D. M. Y., & Bray, S. R. (2019b). Effects of mental fatigue on exercise intentions and behavior. *Annals of Behavioral Medicine*, *53,* 405–414. https://doi.org/10.1093/abm/kay052

Brown, D. M. Y., Graham, J. D., Innes, K. I., Harris, S., Flemington, A., & Bray, S. R. (2020). Effects of prior cognitive exertion on physical performance: A systematic review and meta-analysis. *Sports Medicine*, *50*, 497–529. https://doi.org/10.1007/s40279-019-01204-8

Brownsberger, J., Edwards, A., Crowther, R., & Cottrell, D. (2013). Impact of mental fatigue on self-paced exercise. *International Journal of Sports Medicine*, *34*, 1029–1036. https://doi.org/10.1055/s-0033-1343402

Buckley, J., Cohen, J. D., Kramer, A. F., McAuley, E., & Mullen, S. P. (2014). Cognitive control in the self-regulation of physical activity and sedentary behavior. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00747

Burnley, M., & Jones, A. M. (2007). Oxygen uptake kinetics as a determinant of sports performance. *European Journal of Sport Science*, *7*, 63–79. https://doi.org/10.1080/17461390701456148

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*, 215–222. https://doi.org/10.1016/S1364-6613(00)01483-2

Cabanac, M. (1986). Money versus pain: Experimental study of a conflict in humans. *Journal of the Experimental Analysis of Behavior*, *46*, 37–44. https://doi.org/10.1901/jeab.1986.46-37

Carter, E. C., Kofler, L. M., Forster, D. E., & McCullough, M. E. (2015). A series of meta-analytic tests of the depletion effect: Self-control does not seem to rely on a limited resource. *Journal of Experimental Psychology: General*, *144*, 796–815. https://doi.org/10.1037/xge0000083

Carter, E. C., & McCullough, M. E. (2014). Publication bias and the limited strength model of self-control: Has the evidence for ego depletion been overestimated? *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00823

Carver, C. S., & Scheier, M. F. (2001). *On the Self-Regulation of Behavior*. Cambridge University Press.

Ciarocco, N. J., Sommer, K. L., & Baumeister, R. F. (2001). Ostracism and ego depletion: The strains of silence. *Personality and Social Psychology Bulletin*, *27*, 1156–1163. https://doi.org/10.1177/0146167201279008

Clark, I. E., Goulding, R. P., DiMenna, F. J., Bailey, S. J., Jones, M. I., Fulford, J., McDonagh, S. T. J., Jones, A. M., & Vanhatalo, A. (2019). Time-trial performance is not impaired in either competitive athletes or untrained individuals following a prolonged cognitive task. *European Journal of Applied Physiology*, *119*, 149–161. https://doi.org/10.1007/s00421-018-4009-6

Clarkson, J. J., Hirt, E. R., Jia, L., & Alexander, M. B. (2010). When perception is more than reality: The effects of perceived versus actual resource depletion on self-regulatory behavior. *Journal of Personality and Social Psychology*, *98*, 29–46. https://doi.org/10.1037/a0017539

Coutinho, D., Gonçalves, B., Wong, D. P., Travassos, B., Coutts, A. J., & Sampaio, J. (2018). Exploring the effects of mental and muscular fatigue in soccer players' performance. *Human Movement Science, 58*, 287–296. https://doi.org/10.1016/j.humov.2018.03.004

Crewe, H., Tucker, R., & Noakes, T. D. (2008). The rate of increase in rating of perceived exertion predicts the duration of exercise to fatigue at a fixed power output in different environmental conditions. *European Journal of Applied Physiology*, *103*, 569–577. https://doi.org/10.1007/s00421-008-0741-7

Cunningham, M. R., & Baumeister, R. F. (2016). How to make nothing out of something: Analyses of the impact of study sampling and statistical interpretation in misleading meta-analytic conclusions. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01639

Dang, J. (2018). An updated meta-analysis of the ego depletion effect. *Psychological Research*, *82*, 645–651. https://doi.org/10.1007/s00426-017-0862-x

Dang, J., Barker, P., Baumert, A., Bentvelzen, M., Berkman, E., Buchholz, N., Buczny, J., Chen, Z., De Cristofaro, V., de Vries, L., Dewitte, S., Giacomantonio, M., Gong, R., Homan, M., Imhoff, R., Ismail, I., Jia, L., Kubiak, T., Lange, F., … Zinkernagel, A. (2020). A multilab replication of the ego depletion effect. *Social Psychological and Personality Science*, 1948550619887702. https://doi.org/10.1177/1948550619887702

de Ridder, D. T. D., Lensvelt-Mulders, G., Finkenauer, C., Stok, F. M., & Baumeister, R. F. (2012). Taking stock of self-control: A meta-analysis of how trait self-control relates to a wide range of behaviors. *Personality and Social Psychology Review*, *16*, 76–99. https://doi.org/10.1177/1088868311418749

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. https://doi.org/10.1016/j.psychsport.2011.10.004

Duncan, M. J., Fowler, N., George, O., Joyce, S., & Hankey, J. (2015). Mental fatigue negatively influences manual dexterity and anticipation timing but not repeated high-intensity exercise performance in trained adults. *Research in Sports Medicine*, *23*, 1–13. https://doi.org/10.1080/15438627.2014.975811

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

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

Englert, C., & Bertrams, A. (2014). The effect of ego depletion on sprint start reaction time. *Journal of Sport and Exercise Psychology*, *36*, 506–515. https://doi.org/10.1123/jsep.2014-0029

Englert, C., Bertrams, A., Furley, P., & Oudejans, R. R. D. (2015). Is ego depletion associated with increased distractibility? Results from a basketball free throw task. *Psychology of Sport and Exercise*, *18*, 26–31. https://doi.org/10.1016/j.psychsport.2014.12.001

Englert, C., Havik, L., Qian, Z., & Oudejans, R. R. D. (2018). Can you go the extra mile? The effect of ego depletion on endurance performance. *International Journal of Sport Psychology*, *49*, 505–520.

Englert, C., Persaud, B., Oudejans, R., & Bertrams, A. (2015). The influence of ego depletion on sprint start performance in athletes without track and field experience. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01207

Englert, C., & Rummel, J. (2016). I want to keep on exercising but I don't: The negative impact of momentary lacks of self-control on exercise adherence. *Psychology of Sport and Exercise*, *26*, 24–31. https://doi.org/10.1016/j.psychsport.2016.06.001

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

Eston, R., Faulkner, J., St Clair Gibson, A., Noakes, T., & Parfitt, G. (2007). The effect of antecedent fatiguing activity on the relationship between perceived exertion and physiological activity during a constant load exercise task. *Psychophysiology*, *44*, 779–786. https://doi.org/10.1111/j.1469-8986.2007.00558.x

Filipas, L., Gallo, G., Pollastri, L., & Torre, A. L. (2019). Mental fatigue impairs time trial performance in sub-elite under 23 cyclists. *PLOS ONE*, *14*, e0218405. https://doi.org/10.1371/journal.pone.0218405

Filipas, L., Mottola, F., Tagliabue, G., & La Torre, A. (2018). The effect of mentally demanding cognitive tasks on rowing performance in young athletes. *Psychology of Sport and Exercise*, *39*, 52–62. https://doi.org/10.1016/j.psychsport.2018.08.002

Finkel, E. J., Campbell, W. K., Brunell, A. B., Dalton, A. N., Scarbeck, S. J., & Chartrand, T. L. (2006). High-maintenance interaction: Inefficient social coordination impairs self-regulation. *Journal of Personality and Social Psychology*, *91*, 456–475. https://doi.org/10.1037/0022-3514.91.3.456

Finne, E., Englert, C., & Jekauc, D. (2019). On the importance of self-control strength for regular physical activity. *Psychology of Sport and Exercise*, *43*, 165–171. https://doi.org/10.1016/j.psychsport.2019.02.007

Fortes, L. S., Lima-Junior, D. D., Fiorese, L., Nascimento-Júnior, J. R. A., Mortatti, A. L., & Ferreira, M. E. C. (2020). The effect of smartphones and playing video games on decision-making in soccer players: A crossover and randomised study. *Journal of Sports Sciences*, *38*, 552–558. https://doi.org/10.1080/02640414.2020.1715181

Fortes, L. S., Lima-Junior, D., Nascimento-Júnior, J. R. A., Costa, E. C., Matta, M. O., & Ferreira, M. E. C. (2019). Effect of exposure time to smartphone apps on passing decision-making in male soccer athletes. *Psychology of Sport and Exercise*, *44*, 35–41. https://doi.org/10.1016/j.psychsport.2019.05.001

Franco-Alvarenga, P. E., Brietzke, C., Canestri, R., Goethel, M. F., Hettinga, F., Santos, T. M., & Pires, F. O. (2019). Caffeine improved cycling trial performance in mentally fatigued cyclists, regardless of alterations in prefrontal cortex activation. *Physiology & Behavior*, *204*, 41–48. https://doi.org/10.1016/j.physbeh.2019.02.009

Fredholm, B. B., & Svenningsson, P. (2003). Adenosine–dopamine interactions. *Neurology*, *61*, S5. https://doi.org/10.1212/01.WNL.0000095204.89871.FF

Friese, M., Loschelder, D. D., Gieseler, K., Frankenbach, J., & Inzlicht, M. (2019). Is ego depletion real? An analysis of arguments. *Personality and Social Psychology Review*, *23*, 107–131. https://doi.org/10.1177/1088868318762183

Gailliot, M. T., & Baumeister, R. F. (2007). The physiology of willpower: Linking blood glucose to self-control. *Personality and Social Psychology Review*, *11*, 303–327. https://doi.org/10.1177/1088868307303030

Gantois, P., Ferreira, M. E. C., Lima-Junior, D. de, Nakamura, F. Y., Batista, G. R., Fonseca, F. S., & Fortes, L. de S. (2019). Effects of mental fatigue on passing decision-making performance in professional soccer athletes. *European Journal of Sport Science*, *20*, 534–543. https://doi.org/10.1080/17461391.2019.1656781

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

Gieseler, K., Loschelder, D. D., & Friese, M. (2019). What makes for a good theory? How to evaluate a theory using the strength model of self-control as an example. In K. Sassenberg & M. L. W. Vliek (Eds.), *Social Psychology in Action: Evidence-Based Interventions from Theory to Practice* (pp. 3–21). Springer International Publishing. https://doi.org/10.1007/978-3-030-13788-5_1

Graham, J. D., & Bray, S. R. (2012). Imagery and endurance: Does imagery impair performance by depleting self-control strength? *Journal of Imagery Research in Sport and Physical Activity*, *7*. https://doi.org/10.1515/1932-0191.1074

Graham, J. D., & Bray, S. R. (2015). Self-control strength depletion reduces self-efficacy and impairs exercise performance. *Journal of Sport & Exercise Psychology*, *37*, 477–488. https://doi.org/10.1123/jsep.2015-0064

Graham, J. D., Bray, S. R., & Martin Ginis, K. A. (2014). “Pay the piper”: It helps initially, but motivation takes a toll on self-control. *Psychology of Sport and Exercise*, *15*, 89–96. https://doi.org/10.1016/j.psychsport.2013.09.007

Graham, J. D., Ginis, K. M., & Bray, S. (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. https://doi.org/10.1037/spy0000074

Graham, J. D., Li, Y.-C., Bray, S. R., & Cairney, J. (2018). Effects of cognitive control exertion and motor coordination on task self-efficacy and muscular endurance performance in children. *Frontiers in Human Neuroscience*, *12*. https://doi.org/10.3389/fnhum.2018.00379

Graham, J. D., Sonne, M. W. L., & Bray, S. R. (2014). It wears me out just imagining it! Mental imagery leads to muscle fatigue and diminished performance of isometric exercise. *Biological Psychology*, *103*, 1–6. https://doi.org/10.1016/j.biopsycho.2014.07.018

Hagger, M. S., Chatzisarantis, N. L. D., Alberts, H., Anggono, C. O., Batailler, C., Birt, A. R., Brand, R., Brandt, M. J., Brewer, G., Bruyneel, 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. https://doi.org/10.1177/1745691616652873

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin*, *136*, 495–525. https://doi.org/10.1037/a0019486

Hagger, Martin S., Leaver, E., Esser, K., Leung, C.-M., Te Pas, N., Keatley, D. A., Chan, D. K.-C., & Chatzisarantis, N. L. D. (2013). Cue-induced smoking urges deplete cigarette smokers' self-control resources. *Annals of Behavioral Medicine*, *46*, 394–400. https://doi.org/10.1007/s12160-013-9520-8

Harris, S., & Bray, S. R. (2019). Effects of mental fatigue on exercise decision-making. *Psychology of Sport and Exercise*, *44*, 1–8. https://doi.org/10.1016/j.psychsport.2019.04.005

Hayes, A. F. (2017). *Introduction to Mediation, Moderation, and Conditional Process Analysis, Second Edition: A Regression-Based Approach*. New York, NY: Guilford Publications.

Head, J. R., Tenan, M. S., Tweedell, A. J., LaFiandra, M. E., Morelli, F., Wilson, K. M., Ortega, S. V., & Helton, W. S. (2017). Prior Mental Fatigue Impairs Marksmanship Decision Performance. *Frontiers in Physiology*, *8*. https://doi.org/10.3389/fphys.2017.00680

Head, J. R., Tenan, M. S., Tweedell, A. J., Price, T. F., LaFiandra, M. E., & Helton, W. S. (2016). Cognitive fatigue influences time-on-task during bodyweight resistance training exercise. *Frontiers in Physiology*, *7*. https://doi.org/10.3389/fphys.2016.00373

Hofmann, W., Vohs, K. D., & Baumeister, R. F. (2012). What people desire, feel conflicted about, and try to resist in everyday life. *Psychological Science*, *23*, 582–588. https://doi.org/10.1177/0956797612437426

Holgado, D., Zabala, M., & Sanabria, D. (2019). No evidence of the effect of cognitive load on self-paced cycling performance. *PLOS ONE*, *14*, e0217825. https://doi.org/10.1371/journal.pone.0217825

Horstman, D. H., Morgan, W. P., Cymerman, A., & Stokes, J. (1979). Perception of effort during constant work to self-imposed exhaustion. *Perceptual and Motor Skills*, *48*, 1111–1126. https://doi.org/10.2466/pms.1979.48.3c.1111

Inzlicht, M., & Berkman, E. (2015). Six questions for the resource model of control (and some answers). *Social and Personality Psychology Compass*, *9*, 511–524. https://doi.org/10.1111/spc3.12200

Inzlicht, M., & Friese, M. (2019). The past, present, and future of ego depletion. *Social Psychology*, *50*, 370–378. https://doi.org/10.1027/1864-9335/a000398

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. https://doi.org/10.1177/1745691612454134

Inzlicht, M., Schmeichel, B. J., & Macrae, C. N. (2014). Why self-control seems (but may not be) limited. *Trends in Cognitive Sciences*, *18*, 127–133. https://doi.org/10.1016/j.tics.2013.12.009

Inzlicht, M., Werner, K. M., Briskin, J. L., & Roberts, B. (2020). Integrating models of self-regulation [Preprint]. *PsyArXiv*. https://doi.org/10.31234/osf.io/dpjye

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. https://doi.org/10.1177/0956797610384745

Job, V., Walton, G. M., Bernecker, K., & Dweck, C. S. (2013). Beliefs about willpower determine the impact of glucose on self-control. *Proceedings of the National Academy of Sciences*, *110*, 14837–14842. https://doi.org/10.1073/pnas.1313475110

Job, V., Walton, G. M., Bernecker, K., & Dweck, C. S. (2015). Implicit theories about willpower predict self-regulation and grades in everyday life. *Journal of Personality and Social Psychology*, *108*(4), 637–647. https://doi.org/10.1037/pspp0000014

Kosack, M. H., Staiano, W., Folino, R., Hansen, M. B., & Lønbro, S. (2020). The acute effect of mental fatigue on badminton performance in elite players. *International Journal of Sports Physiology and Performance*, 1–7. https://doi.org/10.1123/ijspp.2019-0361

Kotabe, H. P., & Hofmann, W. (2015). On integrating the components of self-control. *Perspectives on Psychological Science*, *10*, 618–638. https://doi.org/10.1177/1745691615593382

Kunrath, Caito André, Cardoso, F., Nakamura, F. Y., & Teoldo, I. (2018). Mental fatigue as a conditioner of the tactical and physical response in soccer players: A pilot study. *Human Movement*, *19*, 16–22. https://doi.org/10.5114/hm.2018.76075

Kunrath, Caito André, Nakamura, F. Y., Roca, A., Tessitore, A., & Teoldo Da Costa, I. (2020). How does mental fatigue affect soccer performance during small-sided games? A cognitive, tactical and physical approach. *Journal of Sports Sciences*, 1–11. https://doi.org/10.1080/02640414.2020.1756681

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. https://doi.org/10.1017/S0140525X12003196

Le Mansec, Y., Dorel, S., Nordez, A., & Jubeau, M. (2019). Is reaction time altered by mental or physical exertion? *European Journal of Applied Physiology*, *119*, 1323–1335. https://doi.org/10.1007/s00421-019-04124-7

Le Mansec, Y., Pageaux, B., Nordez, A., Dorel, S., & Jubeau, M. (2018). Mental fatigue alters the speed and the accuracy of the ball in table tennis. *Journal of Sports Sciences*, *36*, 2751–2759. https://doi.org/10.1080/02640414.2017.1418647

Lopes, T. R., Oliveira, D. M., Simurro, P. B., Akiba, H. T., Nakamura, F. Y., Okano, A. H., Dias, Á. M., & Silva, B. M. (2020). No sex difference in mental fatigue effect on high-level runners' aerobic performance. *Medicine and Science in Sports and Exercise*. https://doi.org/10.1249/MSS.0000000000002346

Lopez, R. B., Vohs, K. D., Wagner, D. D., & Heatherton, T. F. (2015). Self-regulatory strength: Neural mechanisms and implications for training. In *Handbook of Biobehavioral Approaches to Self-Regulation* (pp. 43–54). New York, NY: Springer. https://doi.org/10.1007/978-1-4939-1236-0_4

Luethi, M. S., Friese, M., Binder, J., Boesiger, P., Luechinger, R., & Rasch, B. (2016). Motivational incentives lead to a strong increase in lateral prefrontal activity after self-control exertion. *Social Cognitive and Affective Neuroscience*, *11*, 1618–1626. https://doi.org/10.1093/scan/nsw073

Mackworth, J. F. (1964). Performance decrement in vigilance, threshold, and high-speed perceptual motor tasks. *Canadian Journal of Psychology*, *18*, 209–223. https://doi.org/10.1037/h0083302

MacMahon, C., Hawkins, Z., & Schücker, L. (2019). Beep test performance is influenced by 30 minutes of cognitive work. *Medicine and Science in Sports and Exercise*, *51*, 1928–1934. https://doi.org/10.1249/MSS.0000000000001982

MacMahon, C., Schücker, L., Hagemann, N., & Strauss, B. (2014). Cognitive fatigue effects on physical performance during running. *Journal of Sport and Exercise Psychology*, *36*, 375–381. https://doi.org/10.1123/jsep.2013-0249

Magariño, L. S., & Madhivanan, P. (2019). Cognitive fatigue effects on physical performance: A systematic review and meta-analysis - Correspondence. *Physiology & Behavior*, *198*, 159–160. https://doi.org/10.1016/j.physbeh.2018.05.025

Marcora, S. M. (2008). Do we really need a central governor to explain brain regulation of exercise performance? *European Journal of Applied Physiology*, *104*, 929–931. https://doi.org/10.1007/s00421-008-0818-3

Marcora, S. M. (2010). Counterpoint: Afferent feedback from fatigued locomotor muscles is not an important determinant of endurance exercise performance. *Journal of Applied Physiology*, *108*, 454–456. https://doi.org/10.1152/japplphysiol.00976.2009a

Marcora, S. M., Bosio, A., & de Morree, H. (2008). Locomotor muscle fatigue increases cardiorespiratory responses and reduces performance during intense cycling exercise independently from metabolic stress. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *294*, R874–R883. https://doi.org/10.1152/ajpregu.00678.2007

Marcora, S. M., & Staiano, W. (2010). The limit to exercise tolerance in humans: Mind over muscle? *European Journal of Applied Physiology*, *109*, 763–770. https://doi.org/10.1007/s00421-010-1418-6

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*, 857–864. https://doi.org/10.1152/japplphysiol.91324.2008

Martijn, C., Tenbült, P., Merckelbach, H., Dreezens, E., & de Vries, N. K. (2002). Getting a grip on ourselves: Challenging expectancies about loss of energy after self-control. *Social Cognition*, *20*, 441–460. https://doi.org/10.1521/soco.20.6.441.22978

Martin Ginis, K. A., & Bray, S. R. (2010). Application of the limited strength model of self-regulation to understanding exercise effort, planning and adherence. *Psychology & Health*, *25*, 1147–1160. https://doi.org/10.1080/08870440903111696

Martin, K., Meeusen, R., Thompson, K. G., Keegan, R., & Rattray, B. (2018). Mental fatigue impairs endurance performance: A physiological explanation. *Sports Medicine*, *48*, 2041–2051. https://doi.org/10.1007/s40279-018-0946-9

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*, e0159907. https://doi.org/10.1371/journal.pone.0159907

Martin, K., Thompson, K. G., Keegan, R., Ball, N., & Rattray, B. (2015). Mental fatigue does not affect maximal anaerobic exercise performance. *European Journal of Applied Physiology*, *115*, 715–725. https://doi.org/10.1007/s00421-014-3052-1

Martin, K., Thompson, K. G., Keegan, R., & Rattray, B. (2019). Are individuals who engage in more frequent self-regulation less susceptible to mental fatigue? *Journal of Sport and Exercise Psychology*, *41*, 289–297. https://doi.org/10.1123/jsep.2018-0222

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. https://doi.org/10.1123/jsep.35.3.239

McKenna, M. J., & Hargreaves, M. (2008). Resolving fatigue mechanisms determining exercise performance: Integrative physiology at its finest! *Journal of Applied Physiology*, *104*, 286–287. https://doi.org/10.1152/japplphysiol.01139.2007

McMorris, T., Barwood, M., Hale, B. J., Dicks, M., & Corbett, J. (2018). Cognitive fatigue effects on physical performance: A systematic review and meta-analysis. *Physiology & Behavior*, *188*, 103–107. https://doi.org/10.1016/j.physbeh.2018.01.029

Milyavskaya, M., & Inzlicht, M. (2017). Attentional and motivational mechanisms of self-control. In D. T. D. de Ridder, M. Adriaanse, & K. Fujita (Eds.), *The Routledge International Handbook of Self-Control in Health and Well-Being* (1st ed., pp. 11–23). New York, NY: Routledge. https://doi.org/10.4324/9781315648576-2

Mischel, W., Ayduk, O., Berman, M. G., Casey, B. J., Gotlib, I. H., Jonides, J., Kross, E., Teslovich, T., Wilson, N. L., Zayas, V., & Shoda, Y. (2011). 'Willpower' over the life span: Decomposing self-regulation. *Social Cognitive and Affective Neuroscience, 6*, 252–256. https://doi.org/10.1093/scan/nsq081

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., Houts, R., Poulton, R., Roberts, B. W., Ross, S., Sears, M. R., Thomson, W. M., & Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, *108*, 2693–2698. https://doi.org/10.1073/pnas.1010076108

Molden, D. C., Hui, C. M., Scholer, A. A., Meier, B. P., Noreen, E. E., D'Agostino, P. R., & Martin, V. (2012). Motivational versus metabolic effects of carbohydrates on self-control. *Psychological Science, 23*, 1137–1144. https://doi.org/10.1177/0956797612439069

Montoya, A. K., & Hayes, A. F. (2017). Two-condition within-participant statistical mediation analysis: A path-analytic framework. *Psychological Methods*, *22*, 6–27. https://doi.org/10.1037/met0000086

Moreira, A., Aoki, M. S., Franchini, E., da Silva Machado, D. G., Paludo, A. C., & Okano, A. H. (2018). Mental fatigue impairs technical performance and alters neuroendocrine and autonomic responses in elite young basketball players. *Physiology & Behavior*, *196*, 112–118. https://doi.org/10.1016/j.physbeh.2018.08.015

Muraven, M., & Slessareva, E. (2003). Mechanisms of self-control failure: Motivation and limited resources. *Personality and Social Psychology Bulletin*, *29*, 894–906. https://doi.org/10.1177/0146167203029007008

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as a limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology*, *74*, 774–789. https://doi.org/10.1037/0022-3514.74.3.774

Murtagh, A. M., & Todd, S. A. (2004). Self-regulation: A challenge to the strength model. *Journal of Articles in Support of the Null Hypothesis, 3*, 19–51.

Nakamura, F. Y., Okuno, N. M., Perandini, L. A., S. Caldeira, L. F., Simões, H. G., Cardoso, J. R., & Bishop, D. J. (2008). Critical power can be estimated from nonexhaustive tests based on rating of perceived exertion responses. *Journal of Strength and Conditioning Research*, *22*, 937–943. https://doi.org/10.1519/JSC.0b013e31816a41fa

Noakes, T. D. (2008). Rating of perceived exertion as a predictor of the duration of exercise that remains until exhaustion. *British Journal of Sports Medicine*, *42*, 623. http://dx.doi.org/10.1136/bjsm.2007.043612

Noakes, T. D., & Gibson, A. S. C. (2004). Logical limitations to the “catastrophe” models of fatigue during exercise in humans. *British Journal of Sports Medicine*, *38*, 648–649. https://doi.org/10.1136/bjsm.2003.009761

Nuechterlein, K. H., Parasuraman, R., & Jiang, Q. (1983). Visual sustained attention: Image degradation produces rapid sensitivity decrement over time. *Science*, *220*, 327–329. https://doi.org/10.1126/science.6836276

Otani, H., Kaya, M., Tamaki, A., & Watson, P. (2017). Separate and combined effects of exposure to heat stress and mental fatigue on endurance exercise capacity in the heat. *European Journal of Applied Physiology*, *117*, 119–129. https://doi.org/10.1007/s00421-016-3504-x

Pageaux, B. (2014). The psychobiological model of endurance performance: An effort-based decision-making theory to explain self-paced endurance performance. *Sports Medicine*, *44*, 1319–1320. https://doi.org/10.1007/s40279-014-0198-2

Pageaux, B., & Lepers, R. (2018). The effects of mental fatigue on sport-related performance. In M. Sarkar & S. Marcora (Eds.), *Sport and the Brain: The Science of Preparing, Enduring and Winning, Part C* (Vol. 240, pp. 291–315). Academic Press. https://doi.org/10.1016/bs.pbr.2018.10.004

Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology*, *114*, 1095–1105. https://doi.org/10.1007/s00421-014-2838-5

Pageaux, B., Marcora, S. M., & Lepers, R. (2013). Prolonged mental exertion does not alter neuromuscular function of the knee extensors. *Medicine & Science in Sports & Exercise*, *45*, 2254–2264. https://doi.org/10.1249/MSS.0b013e31829b504a

Pageaux, B., Marcora, S. M., Rozand, V., & Lepers, R. (2015). Mental fatigue induced by prolonged self-regulation does not exacerbate central fatigue during subsequent whole-body endurance exercise. *Frontiers in Human Neuroscience*, *9*. https://doi.org/10.3389/fnhum.2015.00067

Pattyn, N., Van Cutsem, J., Dessy, E., & Mairesse, O. (2018). Bridging exercise science, cognitive psychology, and medical practice: Is “cognitive fatigue” a remake of “the emperor’s new clothes”? *Frontiers in Psychology*, *9*, 1246. https://doi.org/10.3389/fpsyg.2018.01246

Penna, E. M., Filho, E., Campos, B. T., Pires, D. A., Nakamura, F. Y., Mendes, T. T., Lopes, T. R., Smith, M., & Prado, L. S. (2018). Mental fatigue does not affect heart rate recovery but impairs performance in handball players. *Revista Brasileira de Medicina Do Esporte*, *24*, 347–351. https://doi.org/10.1590/1517-869220182405180483

Penna, E. M., Filho, E., Wanner, S. P., Campos, B. T., Quinan, G. R., Mendes, T. T., Smith, M. R., & Prado, L. S. (2018). Mental fatigue impairs physical performance in young swimmers. *Pediatric Exercise Science*, *30*, 208–215. https://doi.org/10.1123/pes.2017-0128

Pfeffer, I., & Strobach, T. (2017). Executive functions, trait self-control, and the intention–behavior gap in physical activity behavior. *Journal of Sport & Exercise Psychology*, *39*, 277–292. https://doi.org/10.1123/jsep.2017-0112

Pires, F. O., Silva-Júnior, F. L., Brietzke, C., Franco-Alvarenga, P. E., Pinheiro, F. A., de França, N. M., Teixeira, S., & Meireles Santos, T. (2018). Mental fatigue alters cortical activation and psychological responses, impairing performance in a distance-based cycling trial. *Frontiers in Physiology*, *9*, 227. https://doi.org/10.3389/fphys.2018.00227

Rebar, A. L., Dimmock, J. A., Rhodes, R. E., & Jackson, B. (2018). A daily diary approach to investigate the effect of ego depletion on intentions and next day behavior. *Psychology of Sport and Exercise*, *39*, 38–44. https://doi.org/10.1016/j.psychsport.2018.07.010

Roussey, G., Gruet, M., Vercruyssen, F., Louis, J., Vallier, J.-M., & Bernard, T. (2018). Interactions between perceived exertion and thermal perception in the heat in endurance athletes. *Journal of Thermal Biology*, *76*, 68–76. https://doi.org/10.1016/j.jtherbio.2018.07.006

Salam, H., Marcora, S. M., & Hopker, J. G. (2018). The effect of mental fatigue on critical power during cycling exercise. *European Journal of Applied Physiology*, *118*, 85–92. https://doi.org/10.1007/s00421-017-3747-1

Salamone, J. D., Correa, M., Yang, J.-H., Rotolo, R., & Presby, R. (2018). Dopamine, effort-based choice, and behavioral economics: Basic and translational research. *Frontiers in Behavioral Neuroscience*, *12*, 52. https://doi.org/10.3389/fnbeh.2018.00052

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). Cambridge, MA: MIT Press. https://doi.org/10.7551/mitpress/9780262013840.003.0002

Schöndube, 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. https://doi.org/10.1016/j.psychsport.2016.11.006

Schücker, L., & MacMahon, C. (2016). Working on a cognitive task does not influence performance in a physical fitness test. *Psychology of Sport and Exercise*, *25*, 1–8. https://doi.org/10.1016/j.psychsport.2016.03.002

Schweimer, J., & Hauber, W. (2006). Dopamine D1 receptors in the anterior cingulate cortex regulate effort-based decision making. *Learning & Memory*, *13*, 777–782. https://doi.org/10.1101/lm.409306

Secher, N. H., Seifert, T., & Van Lieshout, J. J. (2008). Cerebral blood flow and metabolism during exercise: Implications for fatigue. *Journal of Applied Physiology*, *104*, 306–314. https://doi.org/10.1152/japplphysiol.00853.2007

Seeley, E. A., & Gardner, W. L. (2003). The "selfless" and self-regulation: The role of chronic other-orientation in averting self-regulatory depletion. *Self and Identity*, *2*, 103–117. https://doi.org/10.1080/15298860309034

Shaabani, F., Naderi, A., Borella, E., & Calmeiro, L. (2020). Does a brief mindfulness intervention counteract the detrimental effects of ego depletion in basketball free throw under pressure? *Sport, Exercise, and Performance Psychology*, *9*, 197–215. https://doi.org/10.1037/spy0000201

Shin, M., Kim, Y., & Park, S. (2019). Effects of state anxiety and ego depletion on performance change in golf putting: A hierarchical linear model application. *Perceptual and Motor Skills*, *126*, 904–921. https://doi.org/10.1177/0031512519856970

Shortz, A. E., & Mehta, R. K. (2017). Cognitive challenges, aging, and neuromuscular fatigue. *Physiology & Behavior*, *170*, 19–26. https://doi.org/10.1016/j.physbeh.2016.11.034

Shortz, A. E., Pickens, A., Zheng, Q., & Mehta, R. K. (2015). The effect of cognitive fatigue on prefrontal cortex correlates of neuromuscular fatigue in older women. *Journal of NeuroEngineering and Rehabilitation*, *12*, 115. https://doi.org/10.1186/s12984-015-0108-3

Silva-Cavalcante, M. D., Couto, P. G., Azevedo, R. de A., Silva, R. G., Coelho, D. B., Lima-Silva, A. E., & Bertuzzi, R. (2018). Mental fatigue does not alter performance or neuromuscular fatigue development during self-paced exercise in recreationally trained cyclists. *European Journal of Applied Physiology*, *118*, 2477–2487. https://doi.org/10.1007/s00421-018-3974-0

Silva-Júnior, F. L. e, Emanuel, P., Sousa, J., Silva, M., Teixeira, S., Pires, F. O., Machado, S., & Arias-Carrion, O. (2016). Prior acute mental exertion in exercise and sport. *Clinical Practice and Epidemiology in Mental Health*, *12*, 94–107. https://doi.org/10.2174/1745017901612010094

Slimani, M., Znazen, H., Bragazzi, N. L., Zguira, M. S., & Tod, D. (2018). The effect of mental fatigue on cognitive and aerobic performance in adolescent active endurance athletes: Insights from a randomized counterbalanced, cross-over trial. *Journal of Clinical Medicine*, *7*, 510. https://doi.org/10.3390/jcm7120510

Smith, M. R., Coutts, A. J., Merlini, M., Deprez, D., Lenoir, M., & Marcora, S. M. (2016). Mental fatigue impairs soccer-specific physical and technical performance. *Medicine & Science in Sports & Exercise*, *48*, 267–276. https://doi.org/10.1249/MSS.0000000000000762

Smith, M. R., Marcora, S. M., & Coutts, A. J. (2015). Mental fatigue impairs intermittent running performance. *Medicine and Science in Sports and Exercise*, *47*, 1682–1690. https://doi.org/10.1249/MSS.0000000000000592

Smith, M. R., Zeuwts, L., Lenoir, M., Hens, N., Jong, L. M. S. D., & Coutts, A. J. (2016). Mental fatigue impairs soccer-specific decision-making skill. *Journal of Sports Sciences*, *34*, 1297–1304. https://doi.org/10.1080/02640414.2016.1156241

Staiano, W., Bosio, A., de Morree, H. M., Rampinini, E., & Marcora, S. (2018). The cardinal exercise stopper: Muscle fatigue, muscle pain or perception of effort? In M. Sarkar & S. Marcora (Eds.), *Sport and the Brain: The Science of Preparing, Enduring and Winning, Part C* (Vol. 240, pp. 175–200). Academic Press.

Stanwood, G. D., Washington, R. A., Shumsky, J. S., & Levitt, P. (2001). Prenatal cocaine exposure produces consistent developmental alterations in dopamine-rich regions of the cerebral cortex. *Neuroscience*, *106*, 5–14. https://doi.org/10.1016/S0306-4522(01)00256-1

Sterelny, K. (2007). Cognitive load and human decision, or, three ways of rolling the rock up hill. In P. Carruthers, S. Laurence, & S. Stich (Eds.), *The Innate Mind: Culture and Cognition* (Vol. 2, pp. 217–233). Oxford University Press. https://www.oxfordscholarship.com/view/10.1093/acprof:oso/9780195310139.001.0001/acprof-9780195310139-chapter-14

Stocker, E., Englert, C., & Seiler, R. (2019). Self-control strength and mindfulness in physical exercise performance: Does a short mindfulness induction compensate for the detrimental ego depletion effect? *Journal of Applied Sport Psychology*, *31*, 324–339. https://doi.org/10.1080/10413200.2018.1471754

Stocker, E., Seiler, R., Schmid, J., & Englert, C. (2020). Hold your strength! Motivation, attention, and emotion as potential psychological mediators between cognitive and physical self-control. *Sport, Exercise, and Performance Psychology*, *9*, 167–182. https://doi.org/10.1037/spy0000173

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

Swick, D., & Jovanovic, J. (2002). Anterior cingulate cortex and the Stroop task: Neuropsychological evidence for topographic specificity. *Neuropsychologia*, *40*, 1240–1253. https://doi.org/10.1016/S0028-3932(01)00226-3

Tyler, J. M., & Burns, K. C. (2008). After depletion: The replenishment of the self's regulatory resources. *Self and Identity*, *7*, 305–321. https://doi.org/10.1080/15298860701799997

Tyler, J. M., & Burns, K. C. (2009). Triggering conservation of the self's regulatory resources. *Basic and Applied Social Psychology*, *31*, 255–266. https://doi.org/10.1080/01973530903058490

Van Cutsem, J., De Pauw, K., Vandervaeren, C., Marcora, S., Meeusen, R., & Roelands, B. (2019). Mental fatigue impairs visuomotor response time in badminton players and controls. *Psychology of Sport and Exercise*, *45*, 101579. https://doi.org/10.1016/j.psychsport.2019.101579

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. https://doi.org/10.1007/s40279-016-0672-0

Van Cutsem, J., Roelands, B., Pluym, B., Tassignon, B., Verschueren, J. O., & Meeusen, R. (2020). Can creatine combat the mental fatigue-associated decrease in visuomotor skills? *Medicine and Science in Sports and Exercise*, *52*, 120–130. https://doi.org/10.1249/mss.0000000000002122

Veness, D., Patterson, S. D., Jeffries, O., & Waldron, M. (2017). The effects of mental fatigue on cricket-relevant performance among elite players. *Journal of Sports Sciences*, *35*, 2461–2467. https://doi.org/10.1080/02640414.2016.1273540

Vohs, K. D., Baumeister, R. F., & Ciarocco, N. J. (2005). Self-regulation and self presentation: Regulatory resource depletion impairs impression management and effortful self-presentation depletes regulatory resources. *Journal of Personality and Social Psychology*, *88*, 632–657. https://doi.org/10.1037/0022-3514.88.4.632

Vrijkotte, S., Meeusen, R., Vandervaeren, C., Buyse, L., Cutsem, J. van, Pattyn, N., & Roelands, B. (2018). Mental fatigue and physical and cognitive performance during a 2-bout exercise test. *International Journal of Sports Physiology and Performance*, *13*, 510–516. https://doi.org/10.1123/ijspp.2016-0797

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

Walsh, M. L. (2000). Whole body fatigue and critical power. *Sports Medicine*, *29*, 153–166. https://doi.org/10.2165/00007256-200029030-00002

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors*, *50*, 433–441. https://doi.org/10.1518/001872008X312152

Williamson, J. W., McColl, R., Mathews, D., Mitchell, J. H., Raven, P. B., & Morgan, W. P. (2001). Hypnotic manipulation of effort sense during dynamic exercise: Cardiovascular responses and brain activation. *Journal of Applied Physiology*, *90*, 1392–1399. https://doi.org/10.1152/jappl.2001.90.4.1392

Williamson, J. W., McColl, R., Mathews, D., Mitchell, J. H., Raven, P. B., & Morgan, W. P. (2002). Brain activation by central command during actual and imagined handgrip under hypnosis. *Journal of Applied Physiology*, *92*, 1317–1324. https://doi.org/10.1152/japplphysiol.00939.2001

Wright, R. A. (2008). Refining the prediction of effort: Brehm's distinction between potential motivation and motivation intensity. *Social and Personality Psychology Compass*, *2*, 682–701. https://doi.org/10.1111/j.1751-9004.2008.00093.x

Xu, X., Demos, K. E., Leahey, T. M., Hart, C. N., Trautvetter, J., Coward, P., Middleton, K. R., & Wing, R. R. (2014). Failure to replicate depletion of self-control. *PLOS ONE*, *9*, e109950. https://doi.org/10.1371/journal.pone.0109950

Yusainy, C., & Lawrence, C. (2015). Brief mindfulness induction could reduce aggression after depletion. *Consciousness and Cognition*, *33*, 125–134. https://doi.org/10.1016/j.concog.2014.12.008

Zering, J. C., Brown, D. M. Y., Graham, J. D., & Bray, S. R. (2017). Cognitive control exertion leads to reductions in peak power output and as well as increased perceived exertion on a graded exercise test to exhaustion. *Journal of Sports Sciences*, *35*, 1799–1807. https://doi.org/10.1080/02640414.2016.1237777

Tables

Table 1a. Studies published in physiology journals by year (*N* = 46)

Year	2009	2010	2011	2012	2013	2014
Author(s)	(Marcora et al., 2009)				(Brownsberger et al., 2013)	(Pageaux et al., 2014)
					(Pageaux et al., 2013)	
Total	1	0	0	0	2	1

Year	2015	2016	2017	2018	2019	2020
Author(s)	(Duncan et al., 2015)	(Azevedo et al., 2016)	(Head et al., 2017)	(Coutinho et al., 2018)	(Clark et al., 2019)	(Kosack et al., 2020)
		(Badin et al., 2016)		(Filipas et al., 2018)	(Filipas et al., 2019)	
	(Martin et al., 2015)	(Head et al., 2016)	(Le Mansec et al., 2018)	(Kunrath et al., 2018)	(Fortes et al., 2019)	
				(Moreira et al., 2018)	(Franco-Alvarenga et al., 2019)	
	(Pageaux et al., 2015)	(Martin et al., 2016)	(Otani et al., 2017)	(Penna, Filho, Campos, et al., 2018)	(Gantois et al., 2019)	(Kunrath et al., 2020)
				(Penna, Filho, Wanner, et al., 2018)	(Holgado et al., 2019)	
	(Shortz et al., 2015)	(Smith, Zeuwts, et al., 2016)	(Shortz & Mehta, 2017)	(Pires et al., 2018)	(Le Mansec et al., 2019)	(Lopes et al., 2020)
				(Roussey et al., 2018)		
	(Smith et al., 2015)	(Smith, Coutts, et al., 2016, Study 1)		(Salam et al., 2018)	(Martin et al., 2019)	
				(Slimani et al., 2018)		
		(Smith, Coutts, et al., 2016, Study 2)	(Veness et al., 2017)	(Silva-Cavalcante et al., 2018)	(Van Cutsem et al., 2019)	(Van Cutsem et al., 2020)
				(Vrijkotte et al., 2018)		
Total	5	7	5	12	9	4

Table 1b. Studies published in sport and exercise psychology journals by year (*N* = 36)

Year	2008	2009	2010	2011	2012	2013	2014
Author(s)	(Bray et al., 2008)		(Martin Ginis & Bray, 2010)	(Bray et al., 2011)	(Dorris et al., 2012, Experiment 1)	(Bray et al., 2013)	(Englert & Bertrams, 2014)
					(Dorris et al., 2012, Experiment 2)		(Graham, Sonne, et al., 2014)
					(Englert & Bertrams, 2012, Study 1)	(McEwan et al., 2013)	(MacMahon et al., 2014)
					(Englert & Bertrams, 2012, Study 2)		(Wagstaff, 2014)
					(Graham & Bray, 2012)		
Total	1	0	1	1	5	2	4

Year	2015	2016	2017	2018	2019	2020
Author(s)	(Englert & Wolff, 2015)		(Boat & Taylor, 2017)	(Brown & Bray, 2019b)*	(Brown & Bray, 2019a)	(Shaabani et al., 2020)

	(Englert, Bertrams, et al., 2015)	(Schücker & MacMahon, 2016, Study 1)	(Boat et al., 2017)	(Boat et al., 2018)	(Harris & Bray, 2019)	
	(Englert, Persaud, et al., 2015)	(Schücker & MacMahon, 2016, Study 2)	(Brown & Bray, 2017a)	(Englert et al., 2018)	(MacMahon et al., 2019)	
				(Graham et al., 2018)		
	(Graham & Bray, 2015)	(Zering et al., 2017)	(Graham et al., 2017)	(Stocker et al., 2019)*	(Shin et al., 2019)	(Stocker et al., 2020)
Total	**4**	**3**	**4**	**5**	**4**	**2**

Table 1c. Studies published in general psychology journals by year (*N* = 17)

Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Author(s)	(Muraven et al., 1998, Study 1)			(Ciarocco et al., 2001)		(Seeley & Gardner, 2003, Study 1)	(Murtagh & Todd, 2004, Study 1)	(Vohs et al., 2005, Study 2)	(Finkel et al., 2006, Study 4)	(Alberts et al., 2007, Study 1)	(Alberts et al., 2008)
						(Seeley & Gardner, 2003, Study 2)				(Alberts et al., 2007, Study 2)	(Tyler & Burns, 2008, Experiment 1)
Total	**1**	**0**	**0**	**1**	**0**	**2**	**1**	**1**	**1**	**2**	**2**

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Author(s)	(Tyler & Burns, 2009, Experiment 2)		(Alberts et al., 2011)		(Hagger et al., 2013, Study 1)	(Xu et al., 2014)	(Yusainy & Lawrence, 2015)					
					(Hagger et al., 2013, Study 2)							
Total	**1**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**0**

Note: Published, peer reviewed studies taken from the Brown et al. (2020) meta-analysis that included literature from the earliest available date up to September 2018. Based on the Brown et al. (2020) eligibility criteria and search terms, an updated search was conducted to include literature up to July 2020. *Study originally published online in the corresponding year in the table but officially published in the year listed in the reference.

Figures

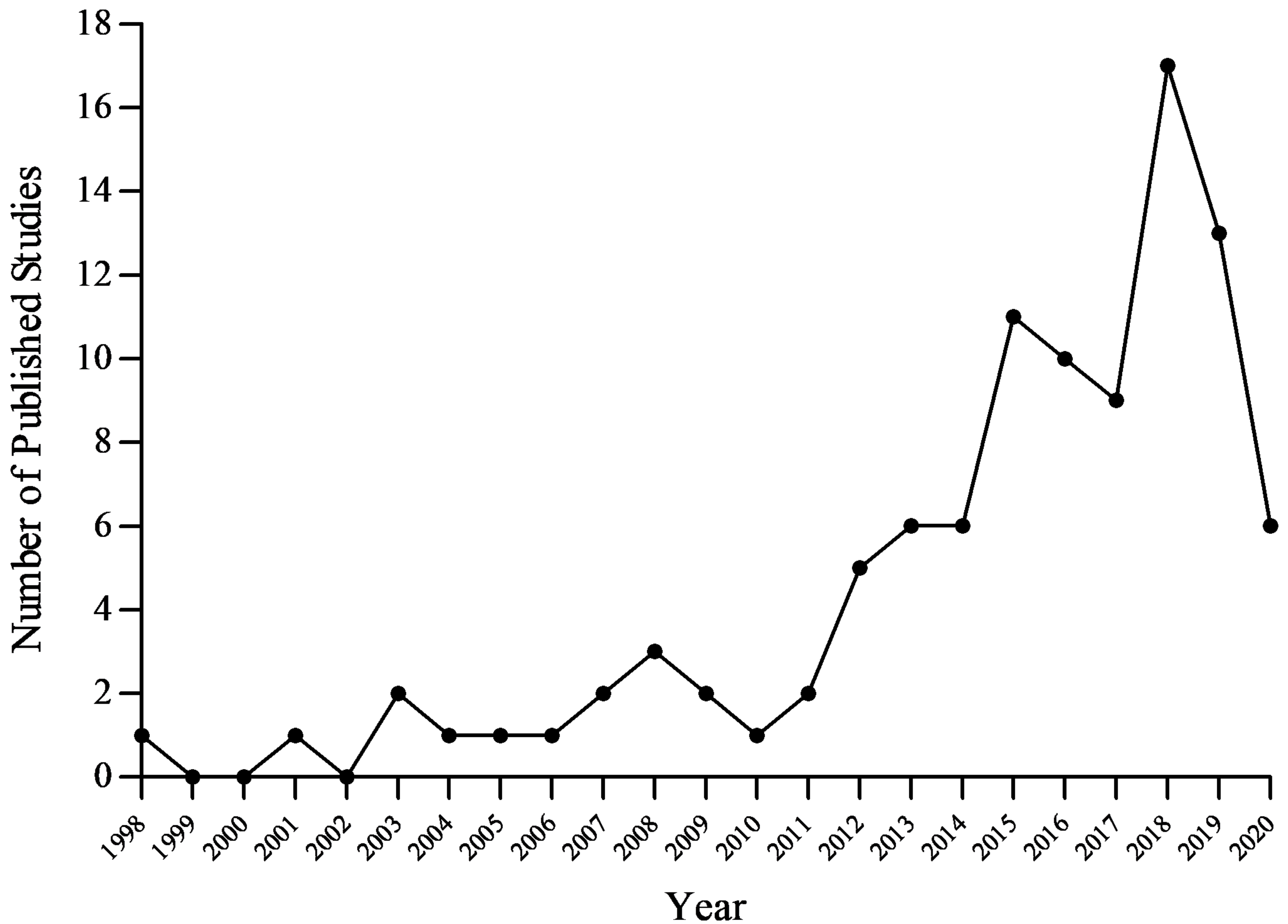

Figure 1. Cognitive exertion – physical performance publication trends (1998-2020) across all disciplines (N = 100), based on the Brown et al. (2020) meta-analysis and an updated search to include literature from the earliest available date up to July 2020.

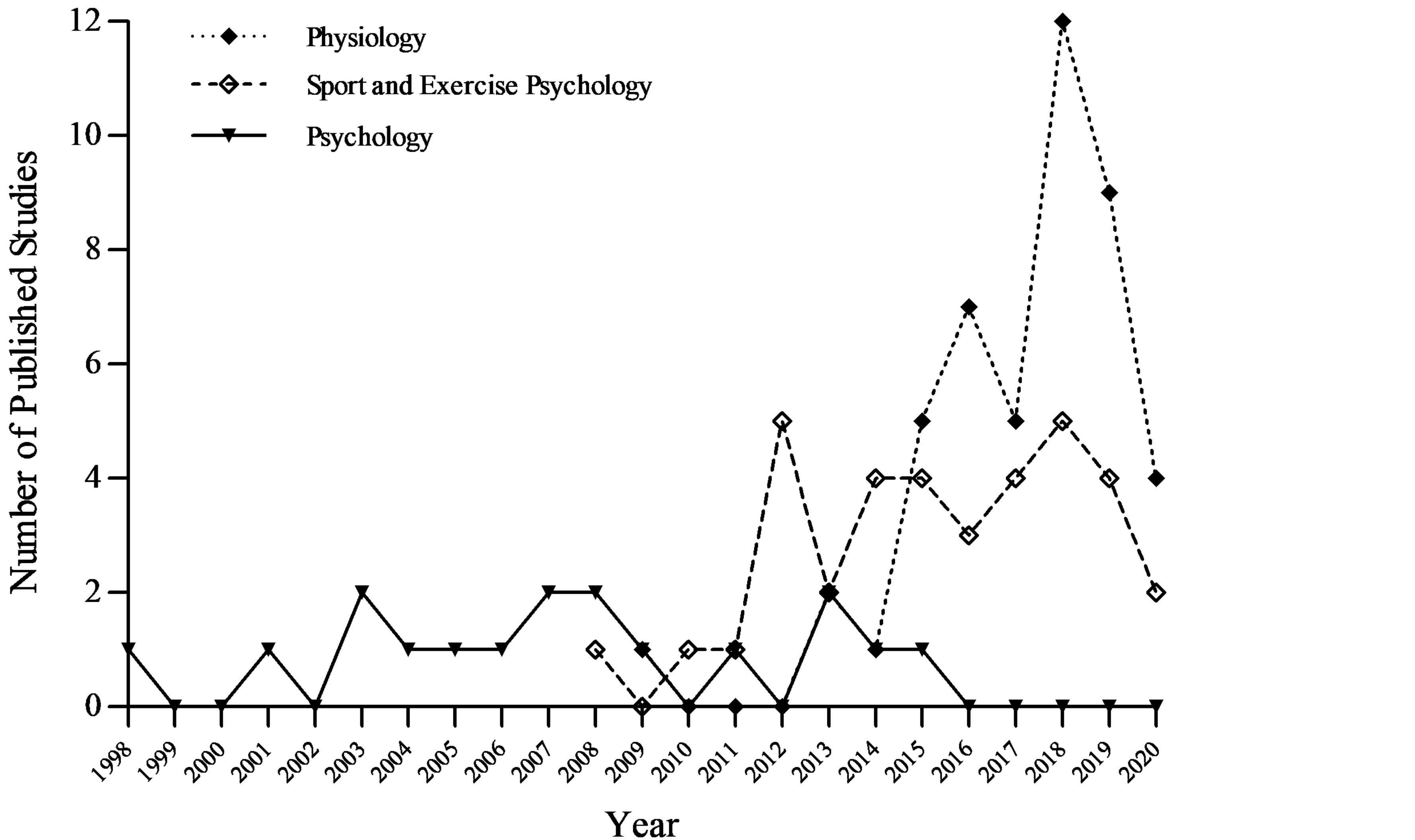

Figure 2. Cognitive exertion – physical performance publication trends (1998-2018) for physiology (N = 46), sport and exercise psychology (N = 36), and psychology (N = 17), based on the Brown et al. (2020) meta-analysis and an updated search to include literature from the earliest available date up to July 2020.